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THE OBJECTIVE ANALYSIS OF HUMIDITY

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October 1965

United Aircraft Corp

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433L SYSTEMS PROGRAM OFFICE
ELECTRONICS SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
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ESSW

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An Upper-Air Humidity Diagnostic and Analysis Technique

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FORWORD

System 433L; project 1.0; task 1.6. This TR has been prepared for United Aircraft Corporation, East Hartford, Connecticut under Subcontract no. 15107 to Contract no. AF 19(628)-3437 by The Travelers Research Center, Inc. The Research Center's publication number is 7463-181. Robert L. Houghten, Lt.Colonel, USAF, is program monitor. The reported research is for the period October 1964 through August 1965. Submitted for approval on 8 October, 1965.

The authors not named on the cover are Paul V. Luty and Keith W. Veigas.

We are happy to acknowledge the valuable programming contributions of Messers Martin Berkowitz, Michael Bzullack, Ronald Grant and Milo McDonald of UAC, the careful preparation of computer input by Mrs. Patricia Bernier of UAC, and the extensive data tabulations and IBM 1620 programming performed by Miss Sally Swanson.

We are gratefull to the personnel of the Computations Division of the National Meteorological Center for collecting the upper-air and surface data used for the development of the warm-season diagnostic relations.

ABSTRACT

In the Northern Hemisphere there are more than five times as many stations reporting surface-synoptic data as there are reporting radiosonde observations. A procedure has been developed to selectively diagnose upper-air humidity from surface observations and to utilize both diagnostic and radiosonde data in an objective analysis of dew-point spread using the successive-approximation technique.

Northern-hemisphere surface-synoptic and radiosonde data from August through October 1964 are used to develop diagnostic relationships between surface-observed variables at a single station and the dew-point spread at the 850-, 700-, 500-, and 400-mb levels above that station for the warm season of the year. The approach consists of two steps: (1) the isolation within a decision-tree framework of those cases for which individual surface-observed variables yield highly reliable estimates of upper-level humidity, and (2) the application of a statistical technique (Regression Estimation of Event Probabilities) to the remaining cases to derive equations yielding probabilities of occurrence of specified categories of dew-point spread. This approach yields useful diagnostic information of variable quality.

The incorporation of diagnostic data obtained from the cold season relationships (derived in earlier work) into a humidity analysis at the 850-, 700- and 500-mb levels is tested using European surface and upper-air data for 22 observation times in February 1962. Sparse data conditions are simulated by withholding a portion of both surface and upper-air data.

Rms errors and contingency table percent correct scores indicate that an improved analysis is obtained by weighting the diagnostic data relative to the radiosonde data. The most appropriate weighting is a function of the reliability of the diagnosis and the data density.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Robert L. Houghten
Lt. Colonel, USAF
Acting System Program Director

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SECTION I

INTRODUCTION

The distribution of radiosonde stations in the Northern Hemisphere is very uneven: few observations of upper-level moisture are available over oceans and sparsely-inhabited land areas. Therefore, upper-air humidity must be inferred from whatever other observational information is available. It might be obtained from routine surface-synoptic observations, provided reliable relationships between upper-level moisture and surface-observed variables can be uncovered. Then, the diagnostic information must be combined with radiosonde data to develop an optimum depiction of the initial-state moisture field. A reliable humidity analysis has many uses, an obvious one being as a source of information for cloud prediction.

The development of techniques to diagnose and predict moisture and clouds has been pursued by many investigators. A discussion of previous research is given in an earlier planning report [1].

In the first phase of the work undertaken by the authors, diagnostic relationships were developed between 850-, 700-, 500-, and 400-mb dew-point spread and surface-observed variables for the cold season of the year (using December, January and February data). This work is reported in [2]. The second phase, reported here, was to develop diagnostic relationships for the warm season of the year (using August, September and October data). The diagnostic approach used for both phases of the study consisted of isolating, within a decision-tree framework, those diagnostic relations from which a highly reliable estimate of moisture could be made, until a point was reached at which the number of direct high-quality relations had been exhausted. The remaining cases (residual sample) were then investigated using a statistical technique called Regression Estimation of Event Probabilities (REEP) [10]. The diagnostic relations derived with REEP are useful but of variable quality. Therefore, an objective analysis procedure was developed to utilize the diagnostic information selectively. A series of tests were conducted with the Successive-Approximation Technique (SAT) analysis procedure to determine the best means of combining the observed and diagnosed data under varying conditions of data density and distribution. The analysis area was limited to Europe; there, progressively sparser data conditions were simulated by withholding both radiosonde and surface data.

SECTION II

DATA PROCESSING

Two data samples were used in the diagnostic and analysis developmental work. Warm-season diagnostic relationships were developed with Northern Hemispheric surface-synoptic observations and upper-air soundings collected by the United States Weather Bureau (USWB) at the National Meteorological Center (NMC) in Suitland, Maryland. The analysis technique was developed and tested with radiosonde and surface data gathered at the 3rd Weather Wing, Global Weather Central (GWC) at Offutt AFB, Nebraska. The data collected at GWC were used earlier to develop the cold-season diagnostic relationships [2].

1. NMC Data

Upper-air soundings (radiosondes) and surface-synoptic observations were recorded on magnetic tape twice daily (00Z and 12Z) by the USWB for the period August 25 through November 14, 1964. For portions of this period (the most lengthy was October 9—18) either surface or radiosonde data were missing.

Because the sample was to be used to develop warm-season diagnostic relationships, selective processing was required to eliminate cases completely unrepresentative of the warm portion of the year. As a consequence, November data were not processed. Further, stations from specific blocks were eliminated from the remainder of the sample (see Fig. 1). Because of these limitations and the data sample characteristics, only 14370 cases were processed, considerably fewer than the cold season sample. In the decision-tree approach, the surface variables are examined individually. We felt that the entire sample was required for developmental work; thus we did not set any portion of the sample aside as independent data for testing the derived warm-season decision-tree relationships. It has been shown [2] that the cold season decision-tree relationships were quite stable. However, limited testing of the warm-season decision-tree relationships was made with hand collected data.

Processing the data consisted of extracting the required surface and upper-air information from multiple basic data tapes, manipulating it into a form

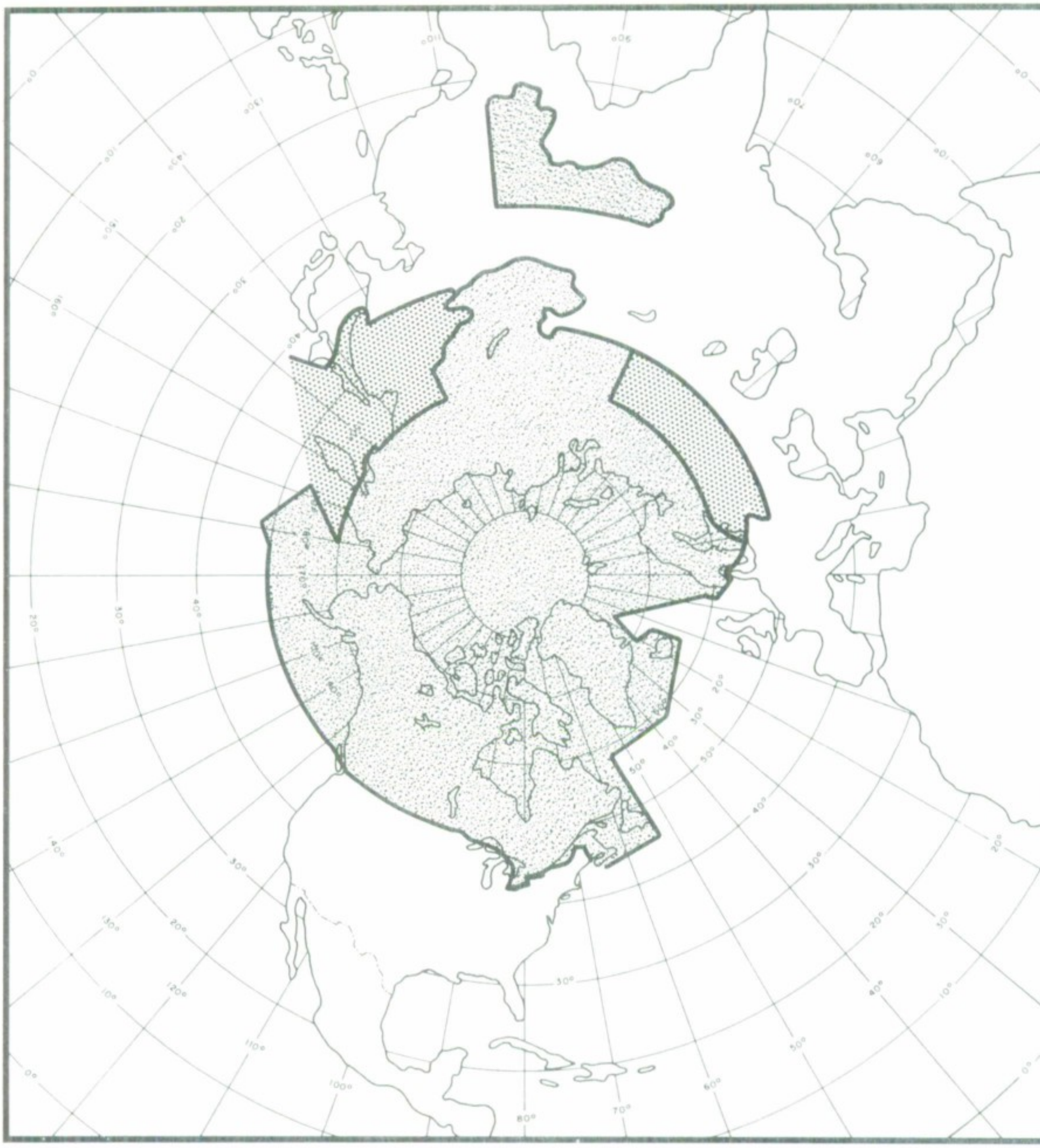

Fig. 1. Northern Hemisphere areas not used in diagnostic study (stipple pattern). Screened areas were omitted only in October.

suitable for evaluation, and merging it into final form on one data tape. Considerable data manipulation was required, because the upper-air data were listed in seven consecutive 00Z observation times followed by seven consecutive 12Z observation times, while the surface data were listed by alternating 00Z and 12Z times. Table I lists the variables that were considered in the decision-tree and statistical evaluations.

TABLE I
SURFACE VARIABLES USED IN DIAGNOSTIC STUDIES

Variable			Usage	
Name	Symbol	Units	Decision tree	Statistical
Wind direction	DD	deg.	no	yes
Wind speed	FF	knot	no	yes
Pressure	P	mb	no	yes
Temperature	T	°C	no	yes
Dew point	T_d	°C	no	yes
Dew-point spread	DPS	°C	no	yes
Visibility	VV	mi	no	yes
Present weather	ww	—	yes	yes
Past weather	W	—	yes	yes
Total cloud amount	N_T	—	yes	yes
Low cloud amount	N_h	—	yes	yes
Low cloud height	h	—	yes	yes
Low cloud type	C_L	—	yes	yes
Middle cloud type	C_M	—	yes	yes
High cloud type	C_H	—	yes	yes
Pressure change	app	—	yes	yes

Because of analysis requirements at NMC, a statistical value of dew-point spread (DPS) was inserted in the upper-air data when a "motorboating" condition[1] occurred. The statistical value used was obtained from Manual for Radiosonde Code [6]. The statistical values of dew-point spread vary from 27°C, for a temperature of 20°C, to 10°C for a temperature of -40°C. The basic upper-air data were such that it was impossible to differentiate between a calculated and an observed dew point. Because the statistically-derived dew-point spread at 400 mb generally was within the range of 10°C to 16°C, it was felt that the resultant decision-tree and REEP relationships would be biased by the grouping within the same dew-point spread interval of very dry (motorboating) cases with cases not nearly so dry. At the 850-, 700-, and 500-mb levels the statistically-derived dew-point spread is usually greater than 15°C for the warm season sample, with the result that the development of the decision-tree and statistical relationships was not hindered.

2. Offutt Data

Data processing required for the analysis developmental testing is described briefly below. A more detailed description of specific computer program functions and analysis technique testing is given in later sections. The processing of the Northern Hemispheric surface-synoptic and upper-air stations and condensation pressure spread (CPS) grid-point data was limited to the area defined in Fig. 2, for the time period 00Z Feb. 6—12Z Feb. 16, 1962 (22 observation times). This time period was selected because all three types of data were available. The area shown in Fig. 2, which includes most of Europe, was chosen for its high density of surface and upper-air stations.

The following data processing steps (See Fig. 3) were required:

(a) Surface-synoptic station data were extracted for the area and observation times of interest. An attempt was made to diagnose dew-point spread at 850-, 700-, and 500-mb at each station using the decision-tree relationships and REEP equations.

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[1] "Motorboating" is the term used to describe the audio signal, transmitted by the radiosonde humidity element, which is so low in frequency that it resembles the sound of a motorboat. The humidity content at a given temperature varies directly with the frequency of the signal; thus a very low frequency corresponds to a low humidity, which cannot be measured accurately.

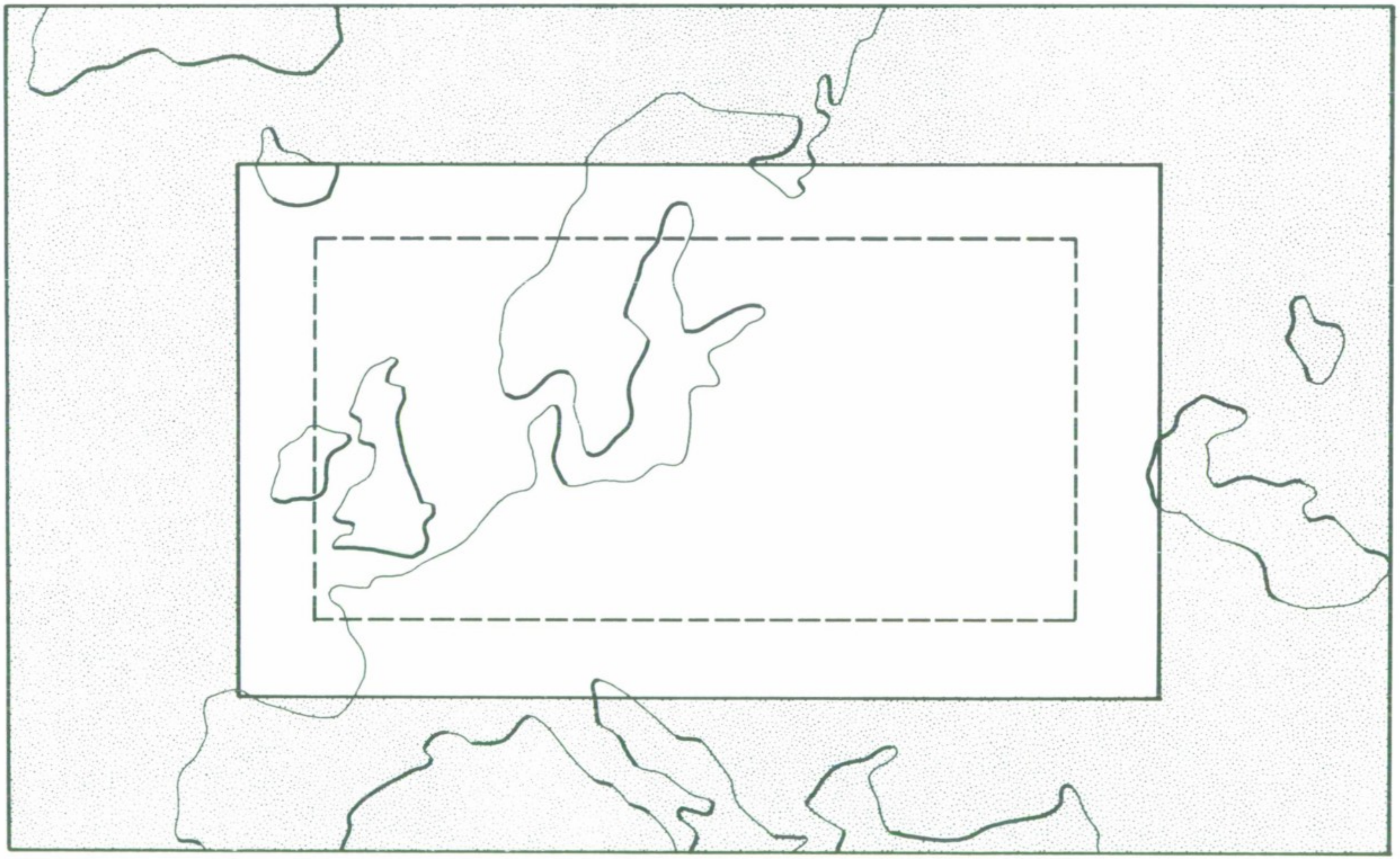

Fig. 2. Area (shaded) used in humidity analysis developmental tests; dashed rectangle encloses verification area.

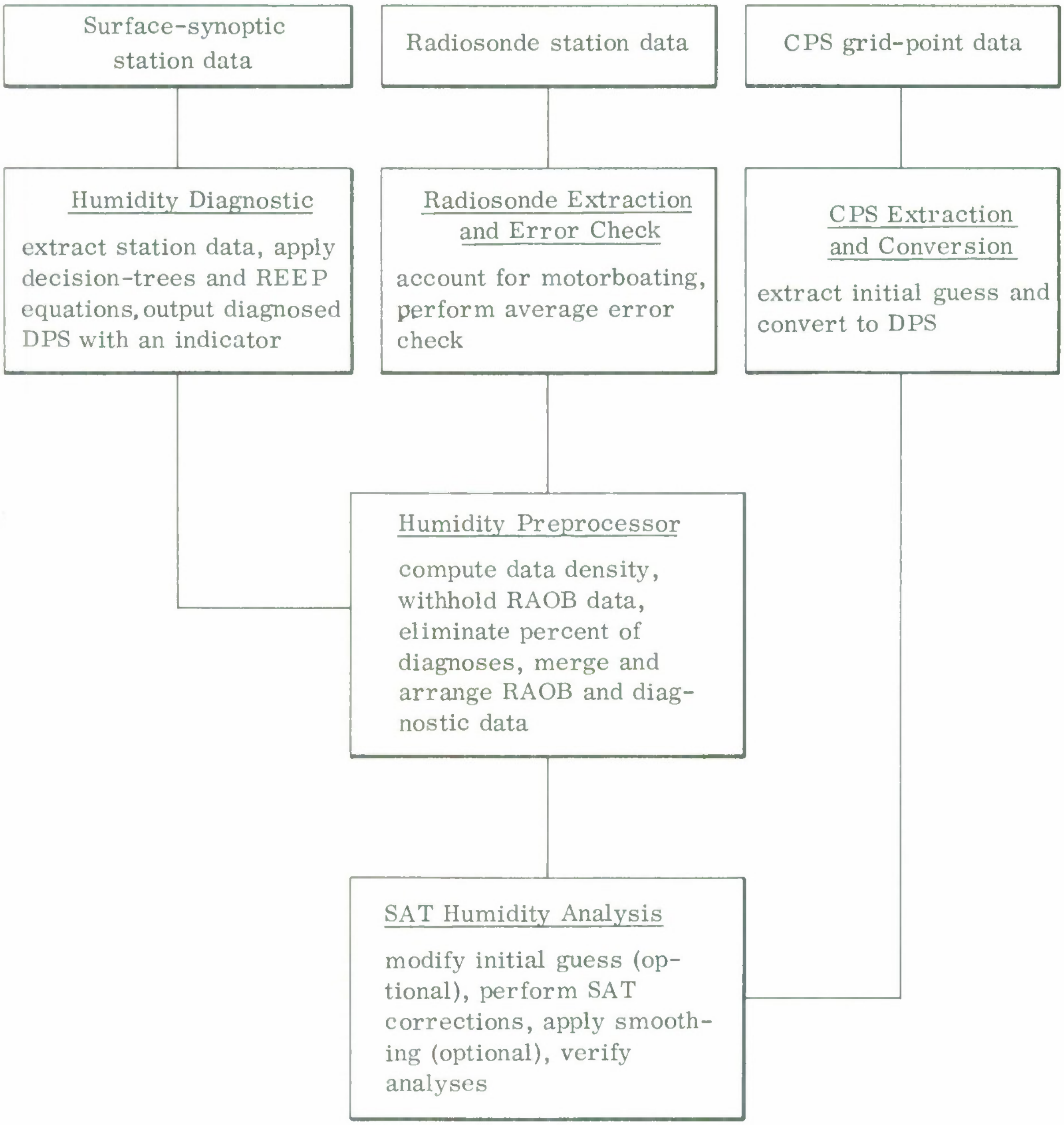

Fig. 3. Data processing steps; computer program titles are underlined.

(b) Radiosonde station data were extracted for the same area and observation times. At any level (850, 700, and 500 mb), when the temperature and height were reported and the dew-point was missing, motorboating was assumed and a dew-point spread of 20°C inserted. All station reports of DPS were error-checked by comparison with the average values of DPS at stations in the vicinity, a reasonable difference being allowed.

(c) Radiosonde and diagnostic information were combined and a variety of data processing functions performed; a measure of station data density and distribution was obtained and data was withheld.

(d) Required CPS grid-point data were extracted and converted to DPS. CPS is a parameter developed at the Scientific Services Section of the USAF Air Weather Service[2] for use in a cloud prediction model. CPS is defined as the pressure difference $p - p_c$, where p is the pressure of an air parcel before lifting and p_c is pressure of the same parcel after condensation has occurred by dry-adiabatic lifting. The expression for CPS is

$$CPS = p_c - p = p \left\{ \left[1 - \frac{\gamma(T - T_d)}{T(\gamma - \gamma_m)} \right]^{c_p/R} - 1 \right\} \tag{II-1}$$

where γ and γ_m are the corresponding dry-adiabatic and mixing-ratio lapse rates, T and T_d are the initial temperature and dew point of the air parcel, c_p is the specific heat at constant pressure, and R is the gas constant for dry air. A CPS value of -100 mb corresponds approximately to a DPS of 10°C.

(e) Radiosonde and diagnostic station data, together with the DPS grid-point data, were then input to the SAT (successive-approximation technique) DPS analysis program in various combinations for developmental testing of the analysis technique.

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[2] Major Earl Kindle, USAF Retired, provided the description "AWS Cloud Forecasting Program" from which this information was extracted.

SECTION III

DECISION-TREE TECHNIQUE

The objective of the decision-tree phase of the study was to select from surface-observed data, variables with a high correlation to moisture content at the (mandatory) 850-, 700-, and 500-mb constant-pressure levels[3] to acquire additional, reliable estimates of humidity which could be used in an objective moisture analysis. Thus, we attempted to find the combination of surface-observed variables that yields the greatest number of reliable estimates of moisture content. There is a large number of combinations: We selected the several most promising by an initial examination of DPS histograms of the variables.

We examined all types of each variable (listed below) to determine which were best related to upper-level dew-point spread (DPS) at each level. This was done by developing a histogram of each type of each variable and evaluating the frequency distribution of DPS for each. The variables considered in the decision-tree phase of the study were: present weather (ww); past weather (W); cloud type (C_L = low, C_M = middle, and C_H = high); cloud amount (N_h = low, and N_T = total); low-cloud height (h); and 3-hr pressure change (app). Table II contains the abridged descriptions of the 100 present-weather types and Table III contains the abridged descriptions of past-weather and low, middle, and high cloud types [7]. This information was taken from a USWB Daily Weather Map.

The evaluation of the histograms consisted of isolating those types of each variable in which a pre-defined percentage of the cases (threshhold value) fell within certain limiting values of DPS. The determination of the threshhold values at each of the pressure levels was based on subjective considerations [2].

Before the decision trees at the 3 levels were developed, the full sample of 14,370 cases was tabulated to determine:

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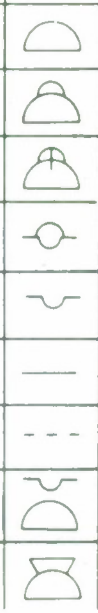
[3] Diagnostic relationships for 400 mb were not developed for reasons explained in Section II.

TABLE II
ABRIDGED DESCRIPTION OF PRESENT-WEATHER TYPES

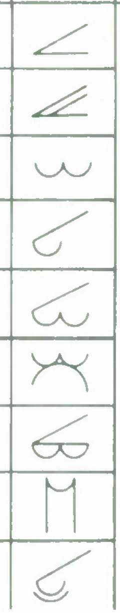
WW PRESENT WEATHER (Descriptions Abridged from W. M. O. Code)

	0	1	2	3	4	5	6	7	8	9
00	Cloud development NOT observed or NOT observable during past hour	Clouds generally dissolving or becoming less developed during past hour	State of sky on the whole unchanged during past hour	Clouds generally forming or developing during past hour	Visibility reduced by smoke	Haze	Widespread dust in suspension in the air, NOT raised by wind, at time of observation	Dust or sand raised by wind, at time of observation	Well developed dust devil(s) within past hour	Dust storm or sand storm within sight of or at station during past hour
10	Light fog	Patches of shallow fog at station, NOT deeper than 6 feet on land	More or less continuous shallow fog at station, NOT deeper than 6 feet on land	Lightning visible, no thunder heard	Precipitation within sight, but NOT reaching the ground	Precipitation within sight, reaching the ground, but distant from station	Precipitation within sight, reaching the ground, near to but NOT at station	Thunder heard, but no precipitation at the station	Squall(s) within sight during past hour	Funnel cloud(s) within sight during past hour
20	Drizzle (NOT freezing and NOT falling as showers) during past hour, but NOT at time of observation	Rain (NOT freezing and NOT falling as showers) during past hour, but NOT at time of observation	Snow (NOT falling as showers) during past hour, but NOT at time of observation	Rain and snow (NOT falling as showers) during past hour, but NOT at time of observation	Freezing drizzle or freezing rain (NOT falling as showers) during past hour, but NOT at time of observation	Showers of rain during past hour, but NOT at time of observation	Showers of snow, or of rain and snow, during past hour, but NOT at time of observation	Showers of hail, or of hail and rain, during past hour, but NOT at time of observation	Fog during past hour, but NOT at time of observation	Thunderstorm (with or without precipitation) during past hour, but NOT at time of obs.
30	Slight or moderate dust storm or sand storm, has decreased during past hour	Slight or moderate dust storm or sand storm, no appreciable change during past hour	Slight or moderate dust storm or sand storm, has increased during past hour	Severe dust storm or sand storm, has decreased during past hour	Severe dust storm or sand storm, no appreciable change during past hour	Severe dust storm or sand storm, has increased during past hour	Slight or moderate drifting snow, generally low	Heavy drifting snow, generally low	Slight or moderate drifting snow, generally high	Heavy drifting snow, generally high
40	Fog at distance at time of observation, but NOT at station during past hour	Fog in patches	Fog, sky discernible, has become thinner during past hour	Fog, sky NOT discernible, has become thinner during past hour	Fog, sky discernible, no appreciable change during past hour	Fog, sky NOT discernible, no appreciable change during past hour	Fog, sky discernible, has begun or become thicker during past hour	Fog, sky NOT discernible, has begun or become thicker during past hour	Fog, depositing rime, sky discernible	Fog, depositing rime, sky NOT discernible
50	Intermittent drizzle (NOT freezing) slight at time of observation	Continuous drizzle (NOT freezing) slight at time of observation	Intermittent drizzle (NOT freezing) moderate at time of observation	Continuous drizzle (NOT freezing), moderate at time of observation	Intermittent drizzle (NOT freezing), thick at time of observation	Continuous drizzle (NOT freezing), thick at time of observation	Slight freezing drizzle	Moderate or thick freezing drizzle	Drizzle and rain, slight	Drizzle and rain, moderate or heavy
60	Intermittent rain (NOT freezing), slight at time of observation	Continuous rain (NOT freezing), slight at time of observation	Intermittent rain (NOT freezing) moderate at time of obs.	Continuous rain (NOT freezing), moderate at time of observation	Intermittent rain (NOT freezing), heavy at time of observation	Continuous rain (NOT freezing), heavy at time of observation	Slight freezing rain	Moderate or heavy freezing rain	Rain or drizzle and snow, slight	Rain or drizzle and snow, moderate or heavy
70	Intermittent fall of snow flakes, slight at time of observation	Continuous fall of snowflakes, slight at time of observation	Intermittent fall of snowflakes, moderate at time of observation	Continuous fall of snowflakes, moderate at time of observation	Intermittent fall of snowflakes, heavy at time of observation	Continuous fall of snowflakes, heavy at time of observation	Ice needles (with or without fog)	Granular snow (with or without fog)	Isolated starlike snow crystals (with or without fog)	Ice pellets (sleet, U. S. definition)
80	Slight rain shower(s)	Moderate or heavy rain shower(s)	Violent rain shower(s)	Slight shower(s) of rain and snow mixed	Moderate or heavy shower(s) of rain and snow mixed	Slight snow shower(s)	Moderate or heavy snow shower(s)	Slight shower(s) of soft or small hail with or without rain, or rain and snow mixed	Moderate or heavy shower(s) of soft or small hail with or without rain, or rain and snow mixed	Slight shower(s) of hail, with or without rain or rain and snow mixed, not associated with thunder
90	Moderate or heavy shower(s) of hail, with or without rain or rain and snow mixed, not associated with thunder	Slight rain at time of observation; thunderstorm during past hour, but NOT at time of observation	Moderate or heavy rain at time of observation; thunderstorm during past hour, but NOT at time of observation	Slight snow or rain and snow mixed or hail at time of observation; thunderstorm during past hour, but not at time of observation	Moderate or heavy snow, or rain and snow mixed or hail at time of observation; thunderstorm during past hour, but NOT at time of obs.	Slight or moderate thunderstorm without hail, but with rain and/or snow at time of obs.	Slight or moderate thunderstorm, with hail at time of observation	Heavy thunderstorm, without hail, but with rain and/or snow at time of observation	Thunderstorm combined with dust storm or sand storm at time of obs.	Heavy thunderstorm with hail at time of observation

TABLE III
ABRIDGED DESCRIPTION OF PAST-WEATHER AND LOW-, MIDDLE-, AND HIGH-CLOUD TYPES



	C_L	DESCRIPTION (Abridged From W.M.O. Code)
1		Cu of fair weather, little vertical development and seemingly flattened
2		Cu of considerable development, generally towering, with or without other Cu or Sc bases all at same level
3		Cb with tops lacking clear-cut outlines, but distinctly not cirriform or anvil-shaped; with or without Cu, Sc, or St
4		Sc formed by spreading out of Cu; Cu often present also
5		Sc not formed by spreading out of Cu
6		St or Fs or both, but no Fs of bad weather
7		Fs and/or Fc of bad weather (scud)
8		Cu and Sc (not formed by spreading out of Cu) with bases at different levels
9		Cb having a clearly fibrous (cirriform) top, often anvil-shaped, with or without Cu, Sc, St, or scud



	C_M	DESCRIPTION (Abridged From W.M.O. Code)
1		Thin As (most of cloud layer semi-transparent)
2		Thick As, greater part sufficiently dense to hide sun (or moon), or Ns
3		Thin Ac, mostly semi-transparent; cloud elements not changing much and at a single level
4		Thin Ac in patches; cloud elements continually changing and/or occurring at more than one level
5		Thin Ac in bands or in a layer gradually spreading over sky and usually thickening as a whole
6		Ac formed by the spreading out of Cu
7		Double-layered Ac, or a thick layer of Ac, not increasing; or Ac with As and/or Ns
8		Ac in the form of Cu-shaped tufts or Ac with turrets
9		Ac of a chaotic sky, usually at different levels; patches of dense Ci are usually present also

	C_H	DESCRIPTION (Abridged From W.M.O. Code)	CLOUD ABBREVIATION
1		Filaments of Ci, or "mares tails," scattered and not increasing	St or Fs-Stratus or Fractostratus
2		Dense Ci in patches or twisted sheaves, usually not increasing, sometimes like remains of Cb; or towers or tufts	Ci-Cirrus
3		Dense Ci, often anvil-shaped, derived from or associated with Cb	Cs-Cirrostratus
4		Ci, often hook-shaped, gradually spreading over the sky and usually thickening as a whole	Cc-Cirrocumulus
5		Ci and Cs, often in converging bands, or Cs alone; generally overspreading and growing denser; the continuous layer not reaching 45° altitude	Ac-Altocumulus
6		Ci and Cs, often in converging bands, or Cs alone; generally overspreading and growing denser; the continuous layer exceeding 45° altitude	As-Altostratus
7		Veil of Cs covering the entire sky	Sc-Stratocumulus
8		Cs not increasing and not covering entire sky	Ns-Nimbostratus
9		Cc alone or Cc with some Ci or Cs, but the Cc being the main cirriform cloud	Cu or Fc-Cumulus or Fractocumulus
			Cb-Cumulonimbus

Code Number	W	PAST WEATHER	
0		Clear or few clouds	Not Plotted
1		Partly cloudy (scattered) or variable sky	Not Plotted
2		Cloudy (broken) or overcast	Not Plotted
3		Sandstorm or duststorm, or drifting or blowing snow	
4		Fog, or smoke, or thick dust haze	
5		Drizzle	
6		Rain	
7		Snow, or rain and snow mixed, or ice pellets (sleet)	
8		Shower(s)	
9		Thunderstorm, with or without precipitation	

(a) the DPS climatology at the 850-, 700-, and 500-mb levels during the warm season (see Fig. 4),

(b) the likelihood of developing useful decision trees by considering each variable separately, and

(c) limitations imposed by the frequency of occurrence of particular surface variables in the warm season.

This will be referred to later.

3. 850-mb Decision Tree

For the 850-mb decision tree, variables were accepted at the first branch of the tree if 60% or more of the cases fell within five consecutive, 1° C DPS intervals; and at the other branches if 55% or more of the cases fell within 5 consecutive, 1° C DPS intervals.

Analysis of the full-sample climatology and individual histograms for the 850-mb level suggested that the variables low-cloud type (C_L), low-cloud amount (N_h), present weather (ww), and past weather (W) contain many mutually-exclusive types well related to the 850-mb humidity. Thus a decision tree was developed in which each surface variable was considered separately. Further (based on the 850-mb climatology of warm-season observations), it was obvious that the diagnostic relations developed for 850 mb would be restricted to those that implied moist conditions, because (a) low-level (850-mb) dryness occurs infrequently and (b) no clear-cut association of low-level dryness to specific types of surface variables has been found.

To find the sequence for utilizing the selected variables that would lead to optimum results, many alternatives were screened. The following sequences, determined by isolating the acceptable relationships, were considered:

(a) low-cloud type, low-cloud amount, present weather, past weather,

(b) low-cloud type, low-cloud amount, past weather, middle-cloud type,

(c) low-cloud type, low-cloud amount, low-cloud height, past weather,

(d) low-cloud type, past weather, present weather,

(e) past weather, low-cloud type, present weather.

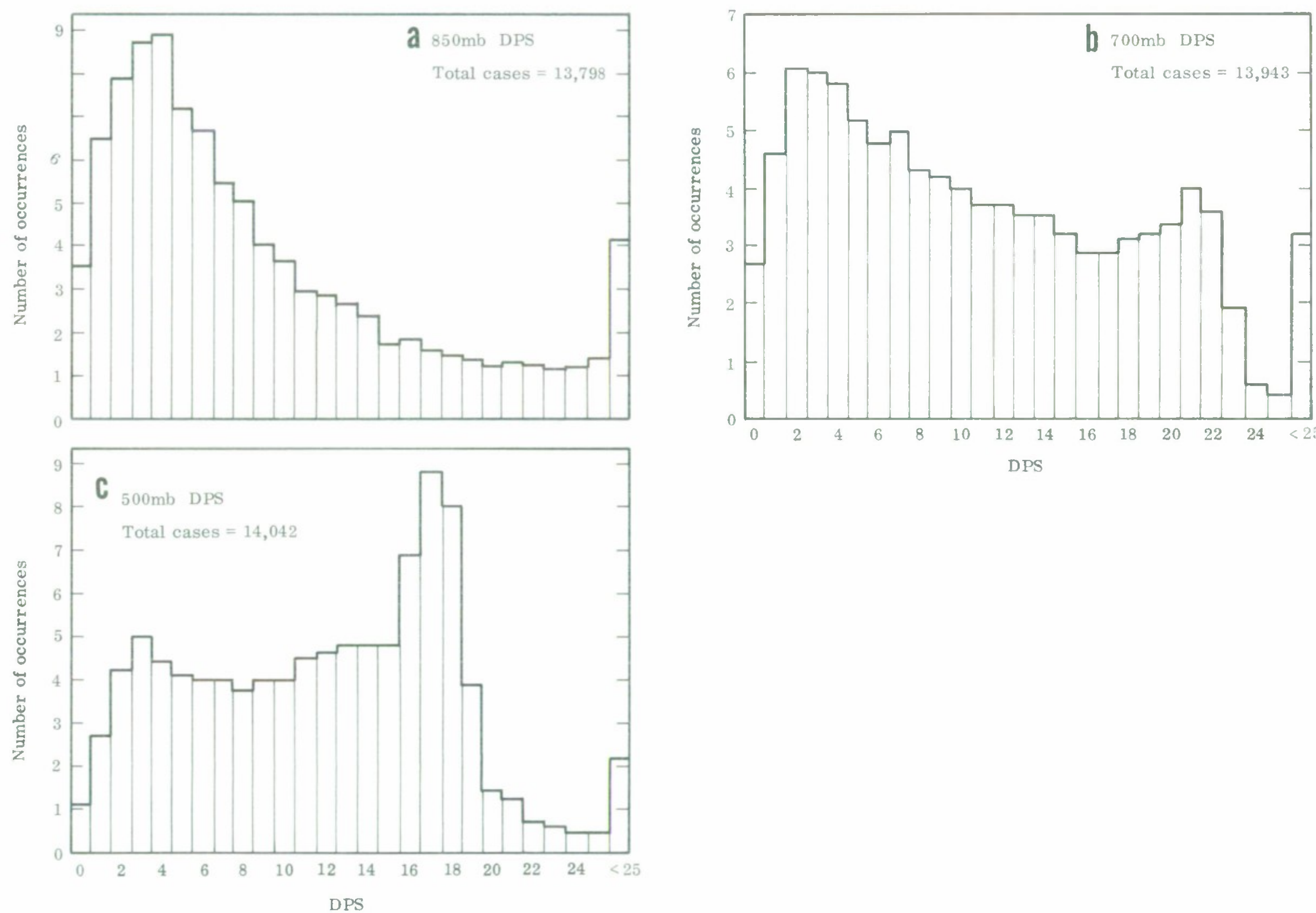


Fig. 4. Climatology of 850-, 700- and 500-mb dew-point spread.

Table IV summarizes the number of cases of each variable accepted (by the criterion described above) in each of the five sequences. Sequence (a) was chosen for further development, even though sequence (c) yielded many more acceptable diagnoses than any other. The reasons for this choice follow. First, a large percentage (over 90%) of the cases in the 3rd and 4th branches of sequence (c) barely met the acceptable requirements, while nearly all of the cases in the same branches of sequence (a) were well above the minimum acceptable level. Second, if there was indeed reliable and usable information in the cases included in sequence (c), but not in sequence (a), then that information would be gleaned from the residual data sample by the REEP technique. Finally, the order in which the surface variables are considered in sequence (a) reflects the general characteristics of warm-season weather — widespread areas of precipitation are less prevalent and convective-type cloudiness is more prevalent than in winter — thus forcing the researcher or the synoptician to rely more heavily on cloudiness for indirect estimates of upper-air humidity. Thus, sequence (a) was chosen and is discussed in detail below.

TABLE IV
NUMBER OF ACCEPTABLE CASES
(850 mb)

Sequence	Order of selection				Total
	1	2	3	4	
(a)	2416(C_L)	2746(N_h)	264(ww)	655(W)	6081
(b)	2416(C_L)	2746(N_h)	756(W)	200(C_M)	6118
(c)	2416(C_L)	2746(N_h)	3018(h)	251(W)	8431
(d)	2416(C_L)	1459(W)	302(ww)	—	4177
(e)	2886(W)	2970(C_L)	250(ww)	—	6106

Figure 5 shows the recommended 850-mb decision tree. The dew-point spread (DPS) value in each subdivision of the decision tree is the midpoint value of the five consecutive 1°C DPS intervals containing the greatest number of cases for each selected variable.

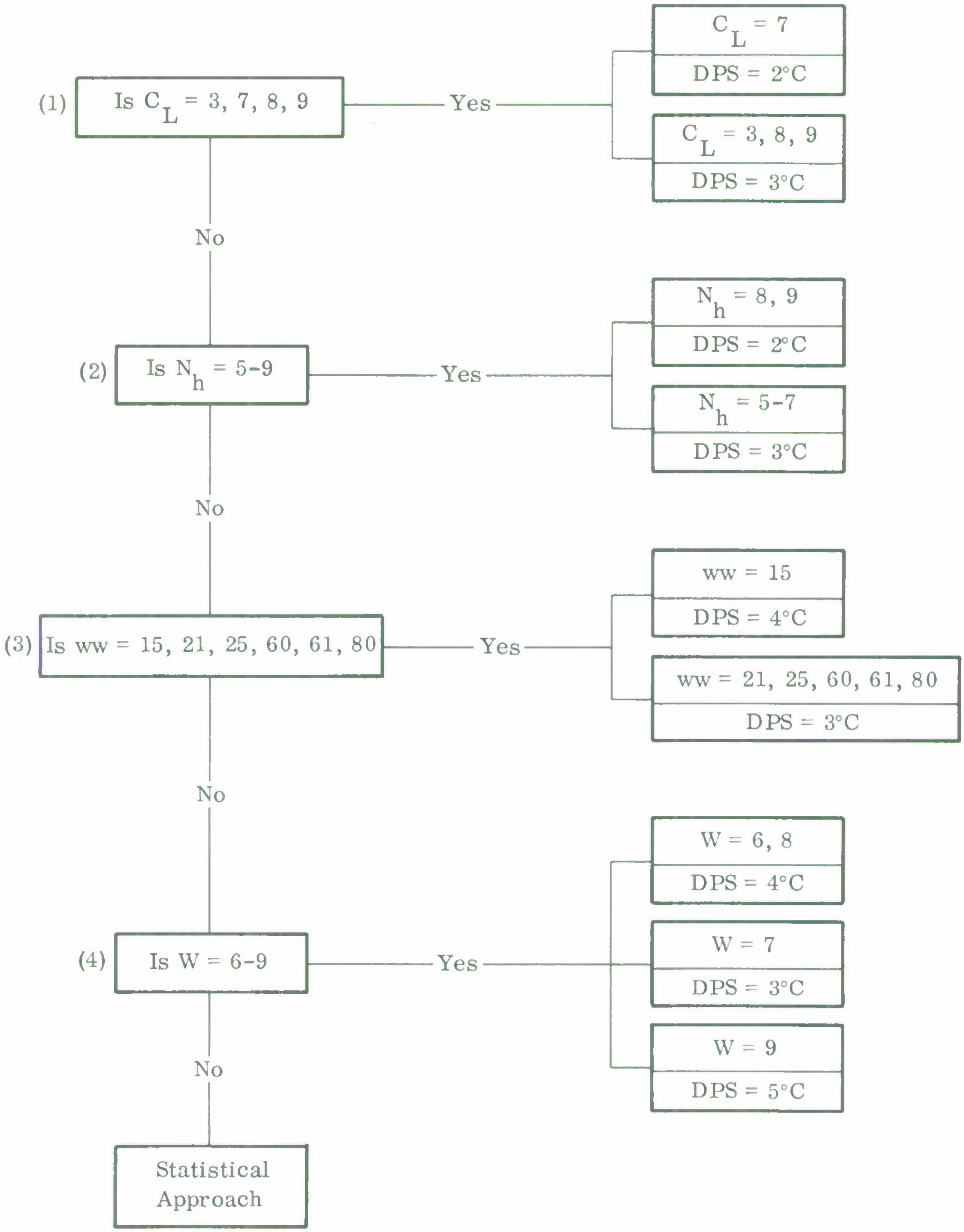


Fig. 5. 850-mb decision tree for warm season.

Table V gives more information about the selected variables individually, such as the modal DPS interval, the midpoint value and percentage of the five consecutive intervals, and the number of cases in the developmental sample in which the particular variable was observed. Figures 6 through 9 are individual histograms of the selected variables.

TABLE V

SEQUENCE (a) SELECTED SURFACE VARIABLES
(850 mb)

Variable	Type	Modal interval DPS (°C)	Five interval Midpoint DPS (°C)	Five interval Percent	Number of diagnoses
C_L	3	3°C	3°C	60	358
	7	1°C	2°C	83	655
	8	2°C	3°C	69	520
	9	2°C	3°C	61	798
N_h	5-7	2°C	3°C	56	1769
	8	1°C	2°C	55	715
	9	1°C	2°C	57	185
ww	15	4°C	4°C	59	40
	21	4°C	3°C	68	39
	25	2°C	3°C	76	85
	60-61	1 and 2°C	3°C	79	69
	80	5°C	3°C	64	25
W	6	4°C	4°C	63	169
	7	3°C	3°C	66	50
	8	4°C	4°C	67	363
	9	3 and 7°C	5°C	53	57

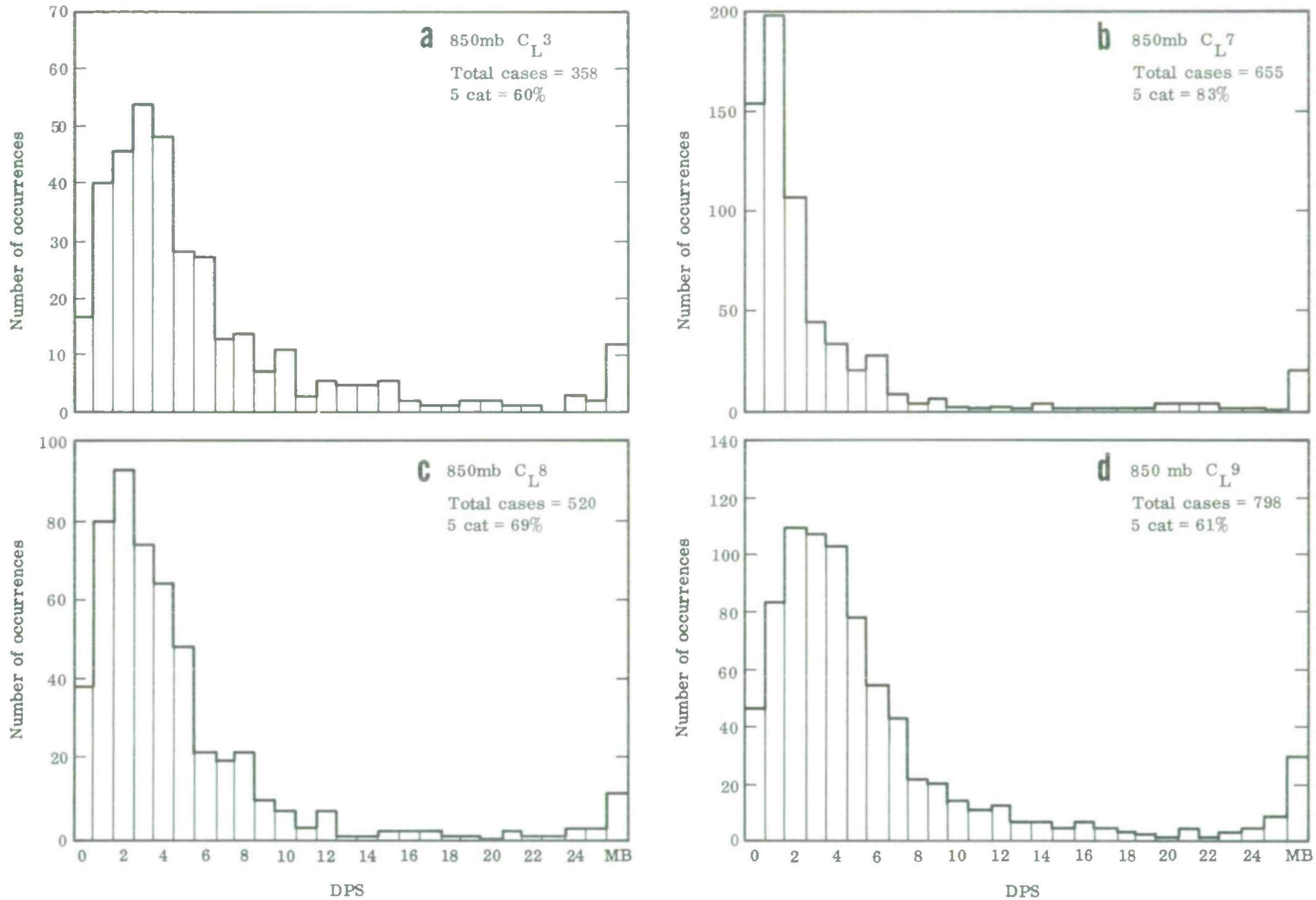


Fig. 6. Distribution of 850-mb dew-point spread for selected low-cloud types.

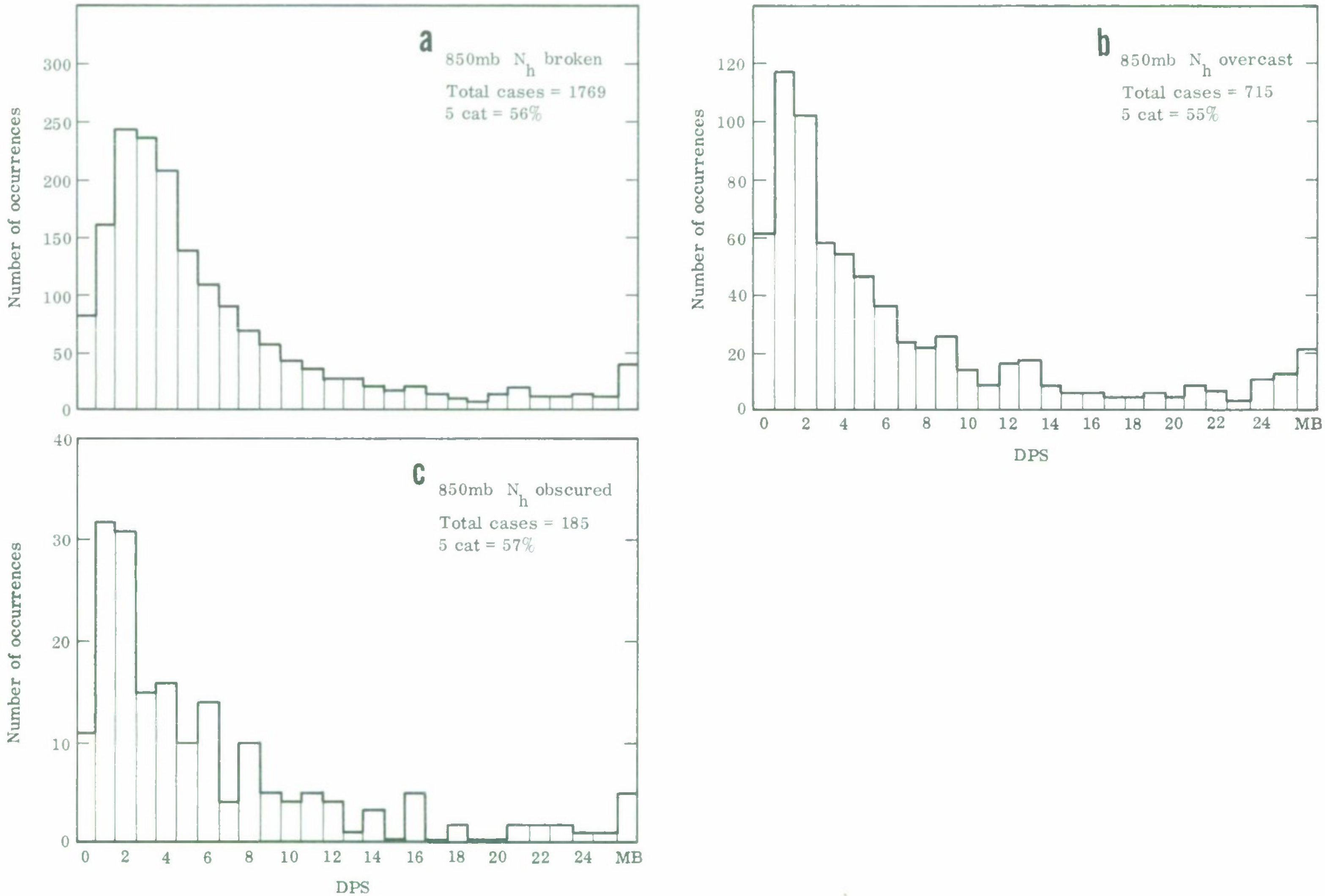


Fig. 7. Distribution of 850-mb dew-point spread for selected low-cloud amount types.

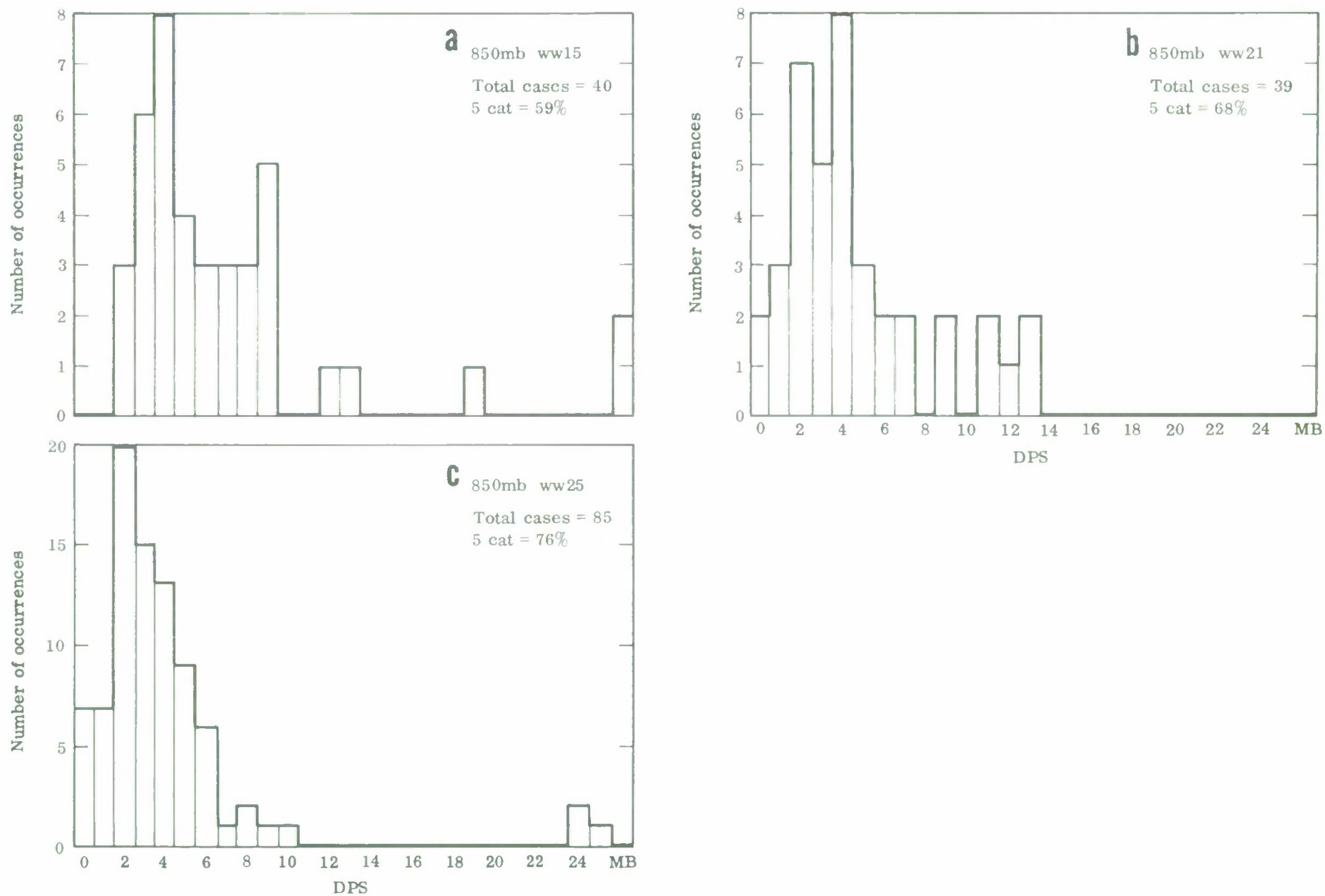


Fig. 8. Distribution of 850-mb dew-point spread for selected present-weather types.

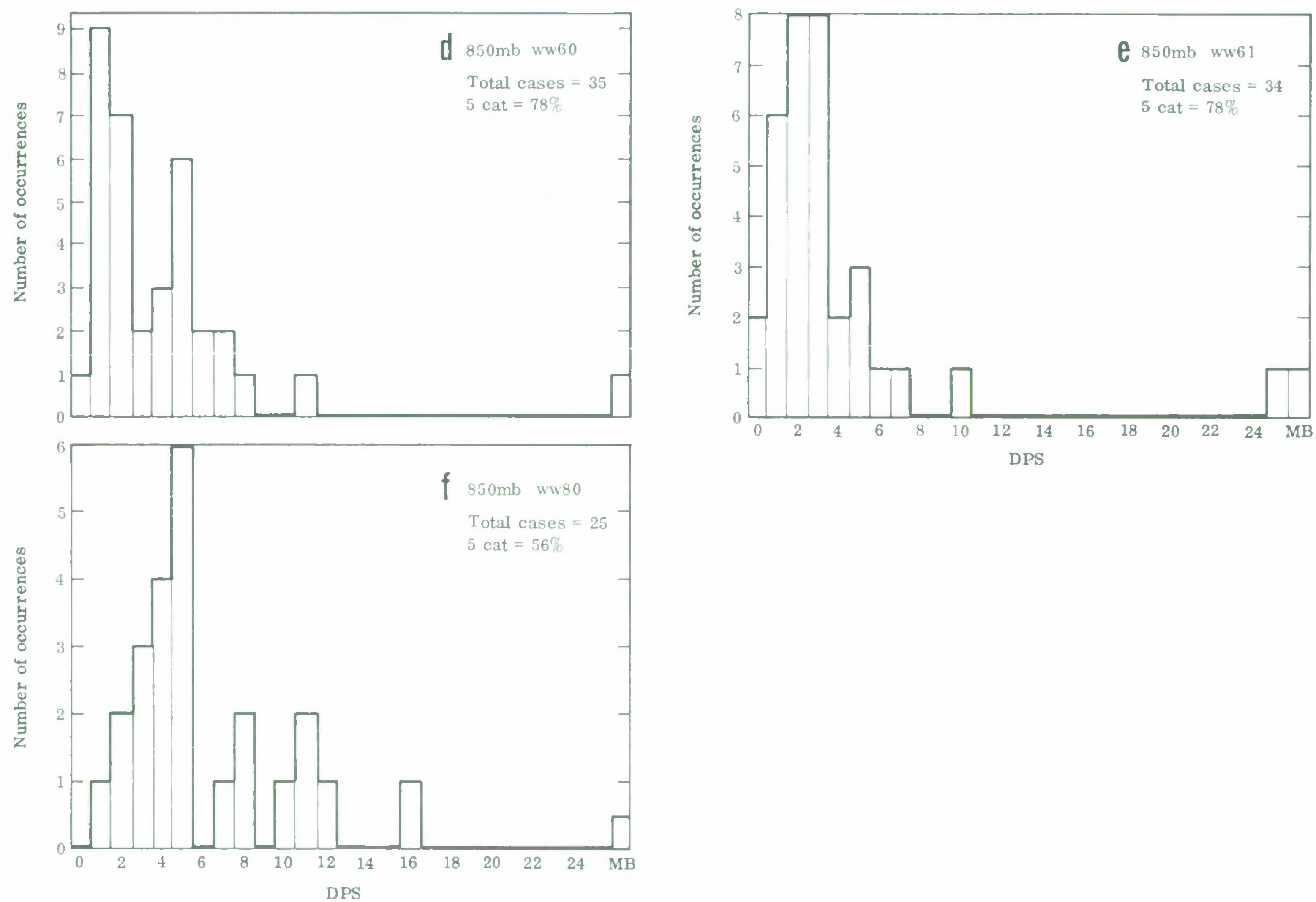


Fig. 8. Concluded

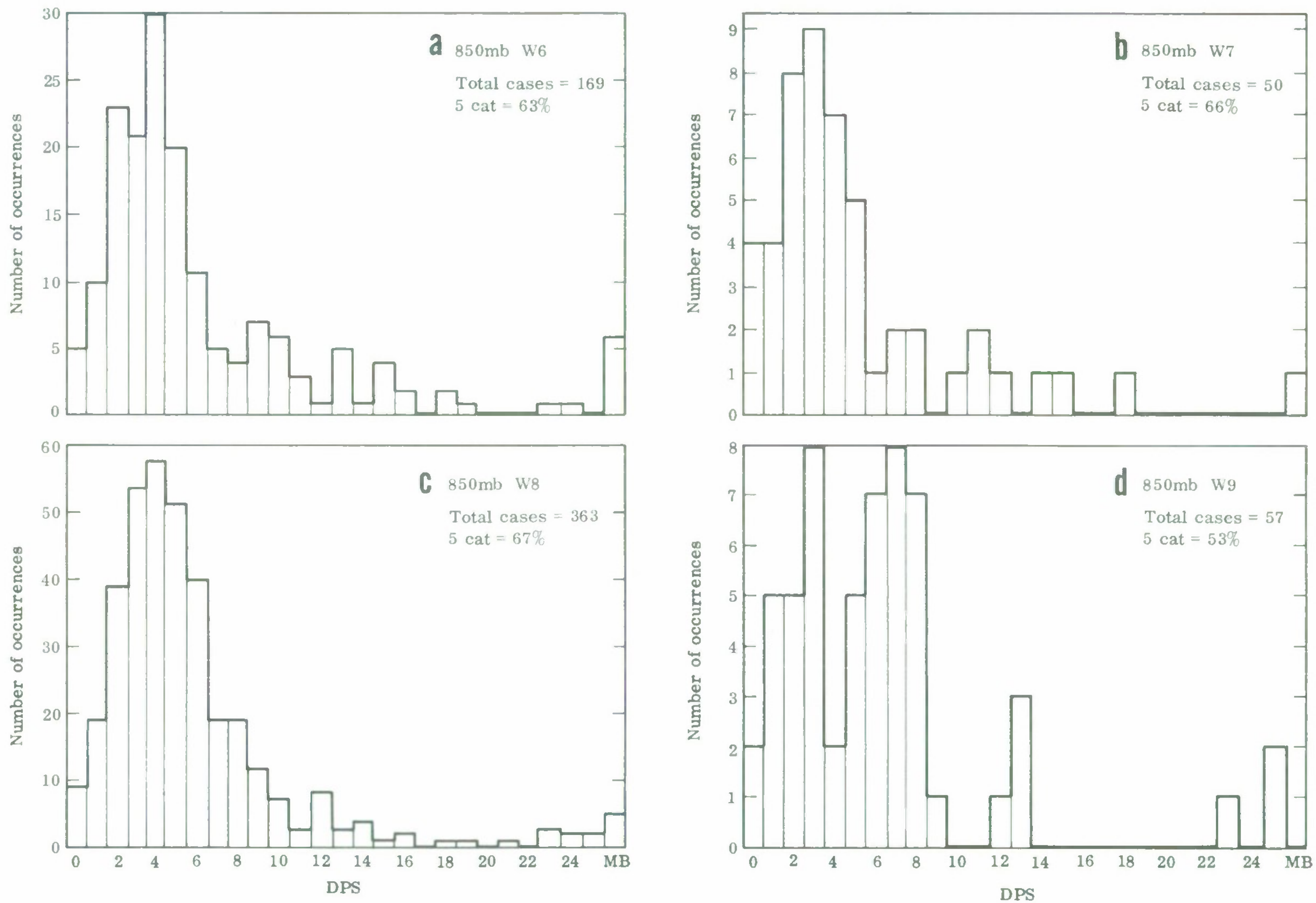


Fig. 9. Distribution of 850-mb dew-point spread for selected past-weather types.

The first variable in sequence (a) is low-cloud type. Of the several types of low cloud, four yielded acceptable estimates of the 850-mb DPS. These are: convective cloudiness of considerable vertical extent (types 3 and 9); multi-layered cumulo-form cloudiness (type 8); and low cloudiness, generally associated with extra-tropical cyclones (type 7). Type 7 implies the most nearly saturated conditions at 850 mb. When the cases containing these low cloud types (types 3, 7, 8, 9) are eliminated from the data sample, the next variable (low cloud amount) is considered.

Of the five categories of low-cloud amount (clear, scattered, broken, overcast and obscured), three yielded acceptable relationships to the 850-mb humidity. They were: broken (5—7/8), overcast (8/8), and obscured (Code 9). [Recall that these amounts of low cloudiness are associated only with stratiform clouds (types 5 and 6) or cumulus clouds of little vertical extent (types 1, 2, and 4).] The data sample was then further reduced by eliminating these cases.

The third variable considered was present weather. The vast majority of weather events (precipitation) occurring in those cases still remaining in the data sample would result from middle clouds not associated with wide-spread low cloudiness. While the five interval percents are quite high for the selected present-weather types, the number of cases of each (see last two columns, Table V) is rather small because widespread precipitation occurs less frequently during the warm months.

Finally, additional useful estimates were gleaned from certain past weather types after the acceptable present weather types had been removed from the sample.

After the acceptable past weather cases were removed from the sample, the remaining cases constituted the "residual sample" from which statistical estimates of 850-mb humidity were obtained using REEP. This is described in subsection 6.

Comparison of the decision tree derived from warm season data with the one derived from cold season data [2] reveals differences and similarities. One basic difference is the order in which the variables are considered. During the cold season, when wide-spread areas of precipitation are more common, the present weather variable is considered first; during the warm season low cloud type is considered first. Another difference is that the variety of present weather types that yield good estimates for the cold season far outnumber those that yield good estimates for the warm season. This is mainly because these present-weather types occur in the summer months too infrequently to yield stable relationships (even when all such events are grouped together based on sound synoptic reasoning). The warm- and cold-season 850-mb decision trees have these points in common: they use the same variables (but in different order), and they provide relationships yielding only moist diagnoses.

4. 700-mb Decision Tree

For the 700-mb decision tree, variables were accepted at the first branch of the tree if 50% or more of the cases fell within five consecutive 1°C DPS intervals; and at the other branches if 45% or more of the cases fell within five consecutive, 1°C DPS intervals.

Analysis of the full-sample climatology and individual histograms for the 700-mb level justified the development of a decision tree considering each surface variable separately. The DPS climatology for the 700-mb level, rather similar to that for 850-mb, showed potential for diagnostic relationships indicative of moist conditions only.

Four sequences for utilizing surface-observed variables were considered at 700-mb. They were:

(a) total-cloud amount, low-cloud type, middle-cloud type, present weather, past weather,

(b) total-cloud amount, past weather, low-cloud type, present weather,

(c) present weather, low-cloud type, middle-cloud type, past weather,

(d) present weather, middle-cloud type, low-cloud type, past weather.

Table VI gives the number of cases containing acceptable relationships in each of the four sequences. Sequence (a) was selected for the 700-mb decision tree because (a) it yielded more acceptable diagnoses and (b) the selected variables yield slightly more reliable estimates, for the most part, in sequence (a). The recommended 700-mb decision tree is discussed in detail below.

TABLE VI

NUMBER OF ACCEPTABLE CASES (700-mb)

Sequence	Order of selection					Total
	1	2	3	4	5	
(a)	2895(N_T)	689(C_L)	303(C_M)	428(ww)	378(W)	4963
(b)	2895(N_T)	616(W)	553(C_L)	325(ww)	—	4389
(c)	1905(ww)	918(C_L)	179(C_M)	510(W)	—	3512
(d)	1905(ww)	569(C_M)	773(C_L)	495(W)	—	3702

Figure 10 is the recommended 700-mb decision tree. As in Fig. 5, the DPS value in each subdivision is the midpoint value. Table VII gives more information about the selected variables individually, such as the modal DPS interval, the midpoint value and percentage of accepted cases, and the number of cases in the developmental sample in which the particular variable was observed. Figures 11 through 14 are individual histograms of the selected variables.

TABLE VII

SEQUENCE (a) SELECTED SURFACE VARIABLES

(700-mb)

Variable	Type	Modal DPS	Midpoint DPS	Five interval percent	Diagnoses
N_T	8	1°C	2°C	56	2801
C_L	7	2°C	3°C	52	78
	9	3°C	5°C	49	590
C_M	1	2°C	4°C	46	50
	6	5°C	5°C	45	242
ww	13	7°C	6°C	59	26
	14	3°C	5°C	44	27
	15	5°C	5°C	48	54
	21	2°C	2°C	77	37
	25	4°C	3°C	45	139
	51	4°C	2°C	47	26
	60	1°C	2°C	83	22
	61	2°C	2°C	54	21
	71	2°C	3°C	80	19
	80	5°C	3°C	52	45
W	6	3°C	3°C	56	237
	7	4°C	2°C	44	62
	9	6°C	4°C	53	68

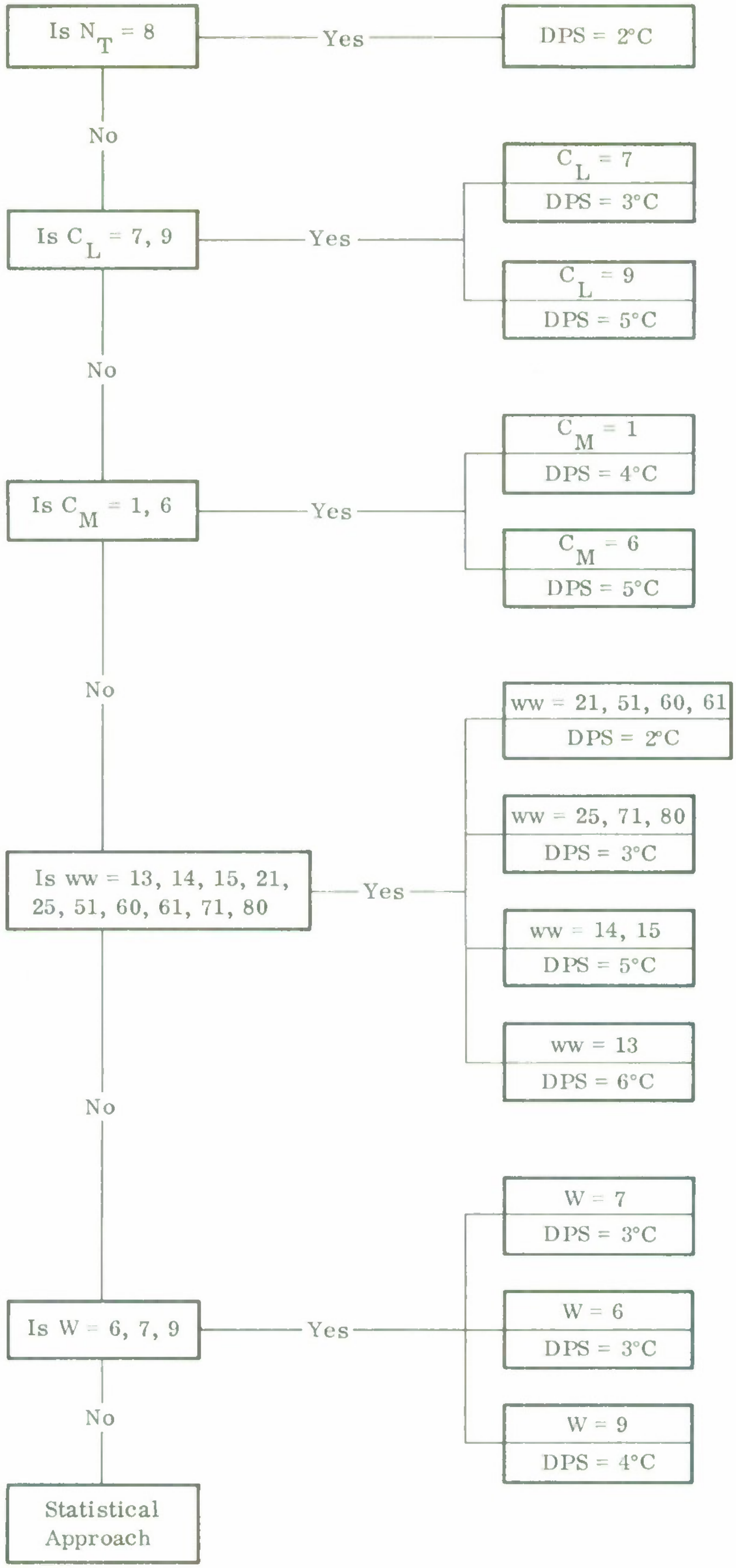


Fig. 10. 700-mb decision tree for warm season.

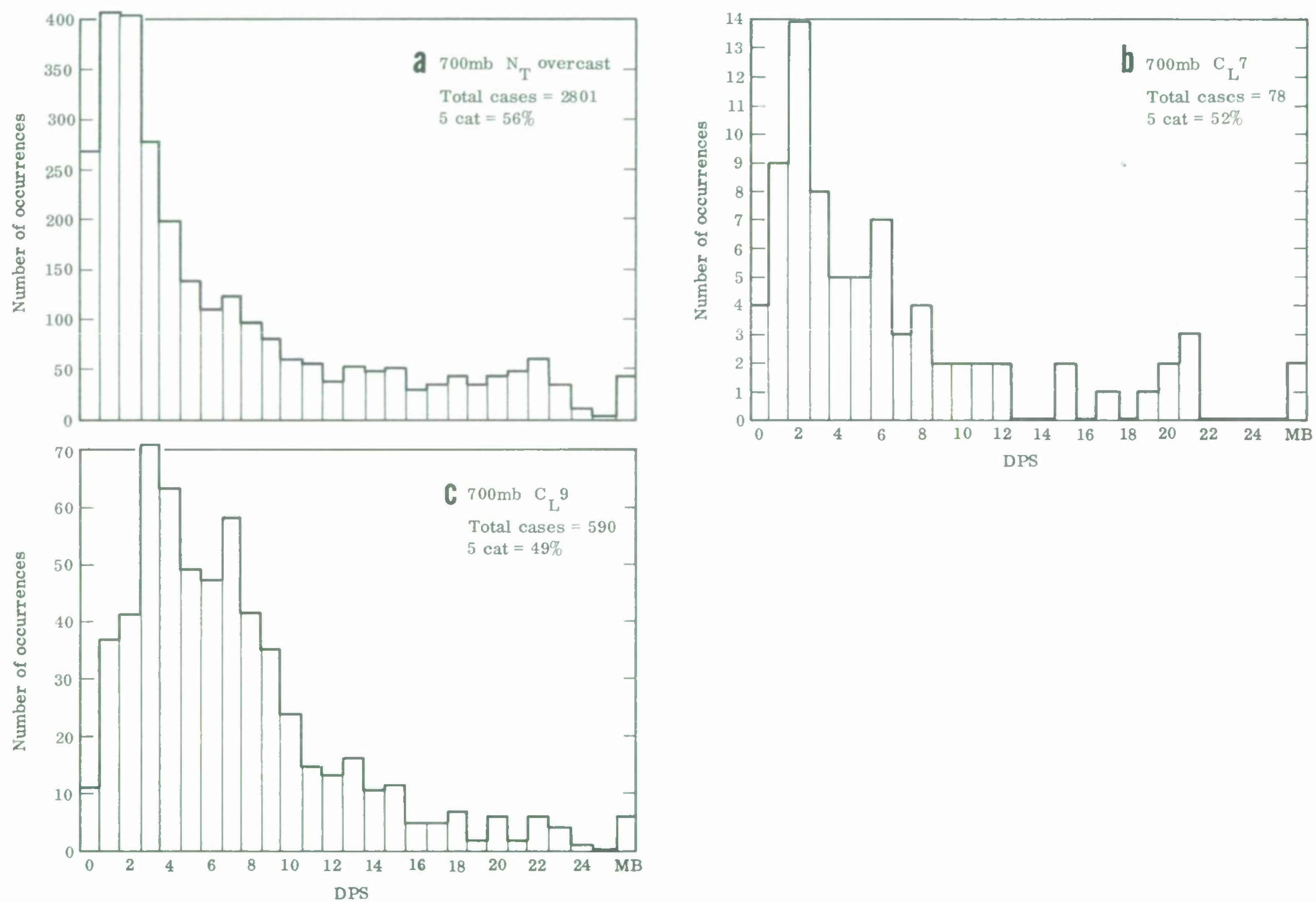


Fig. 11. Distribution of 700-mb dew-point spread for selected total-cloud amount and low-cloud types.

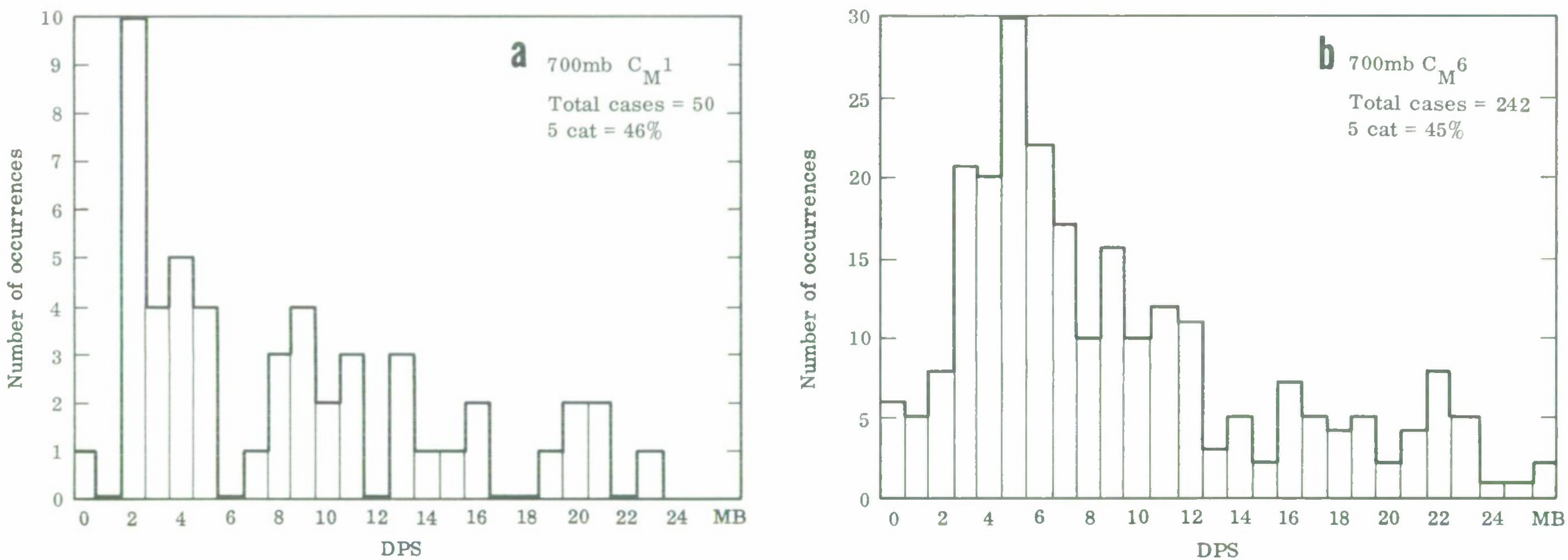


Fig. 12. Distribution of 700-mb dew-point spread for selected middle-cloud types.

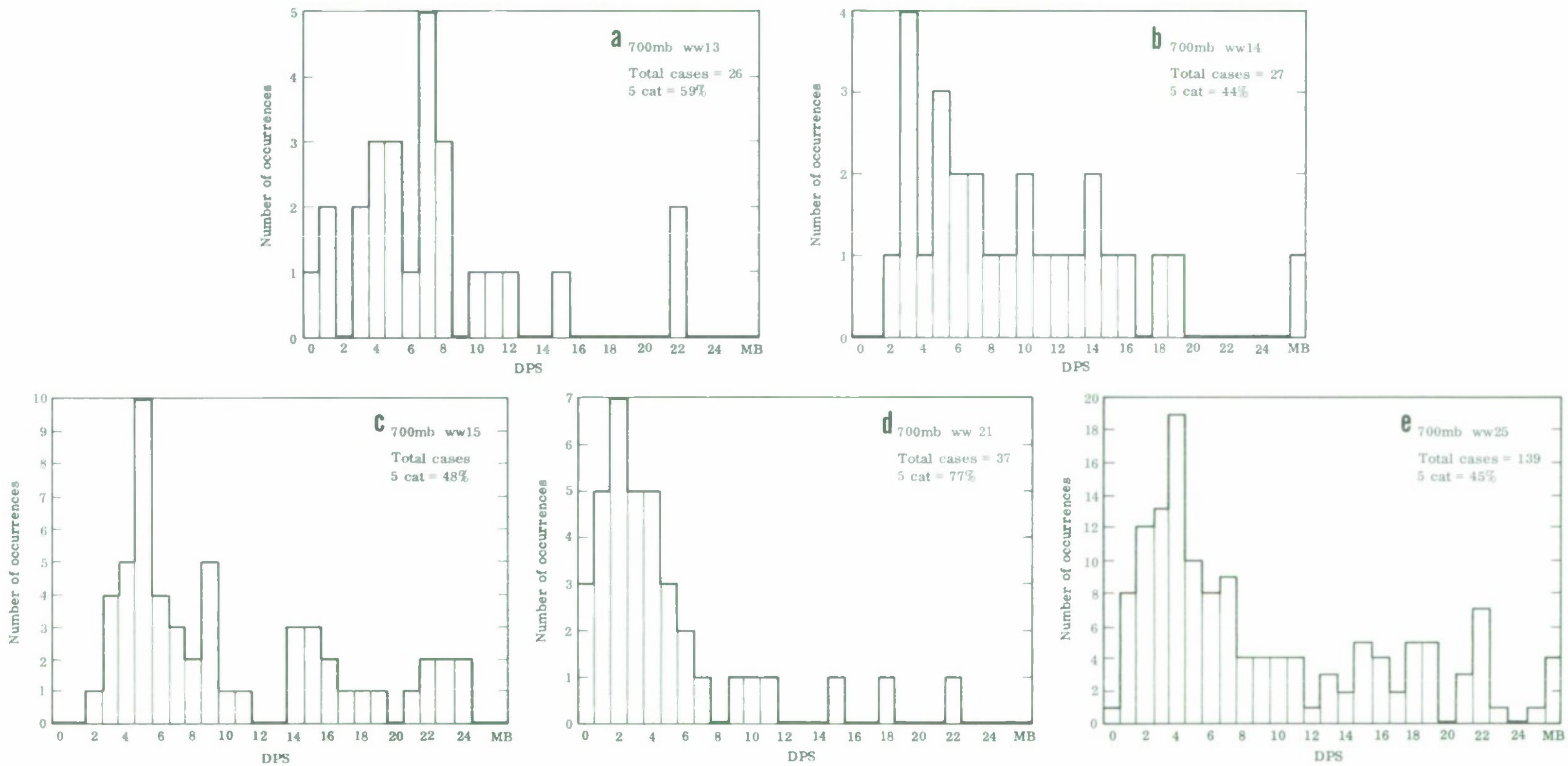


Fig. 13. Distribution of 700-mb dew-point spread for selected present-weather types.

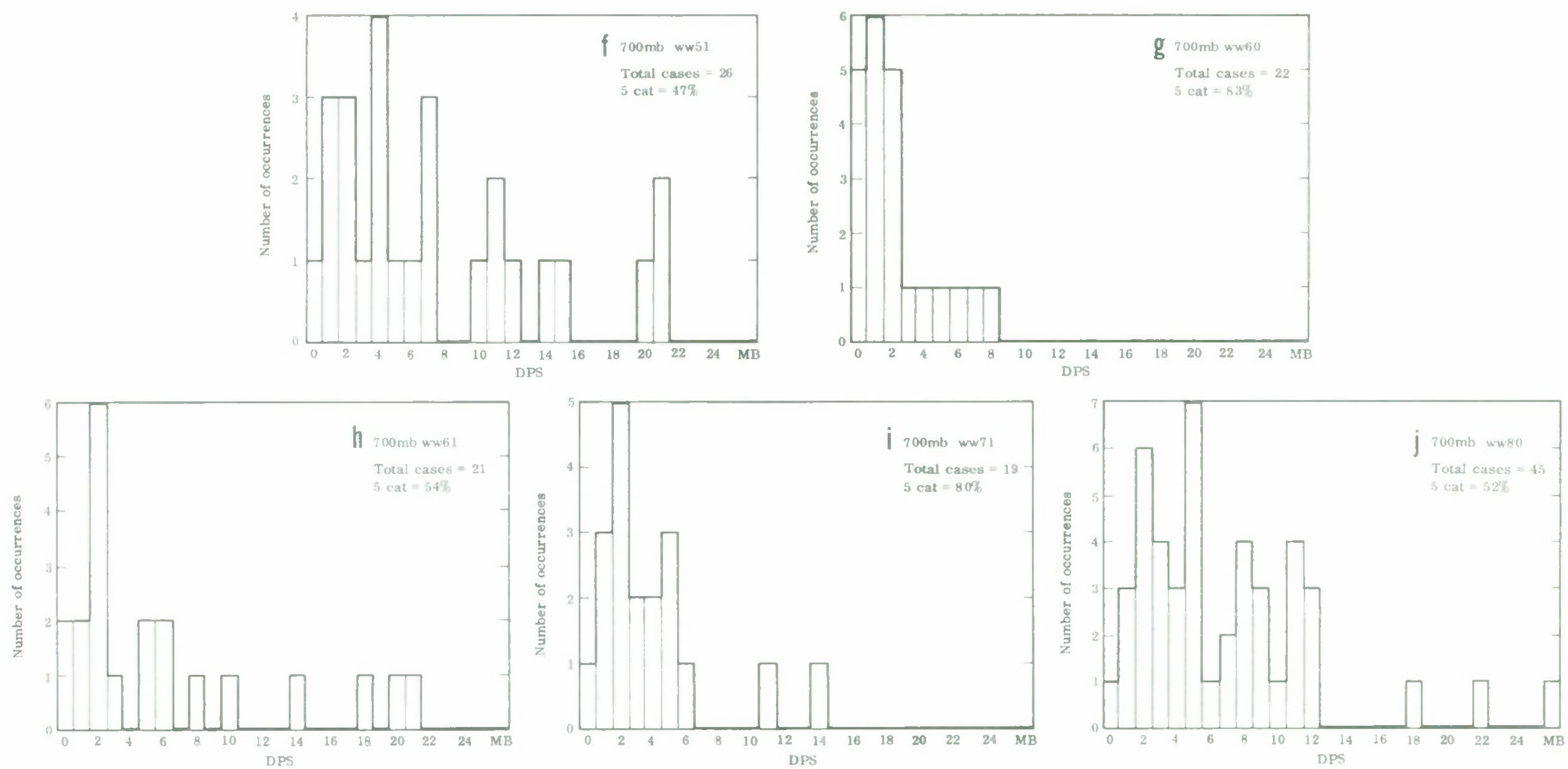


Fig. 13. Concluded

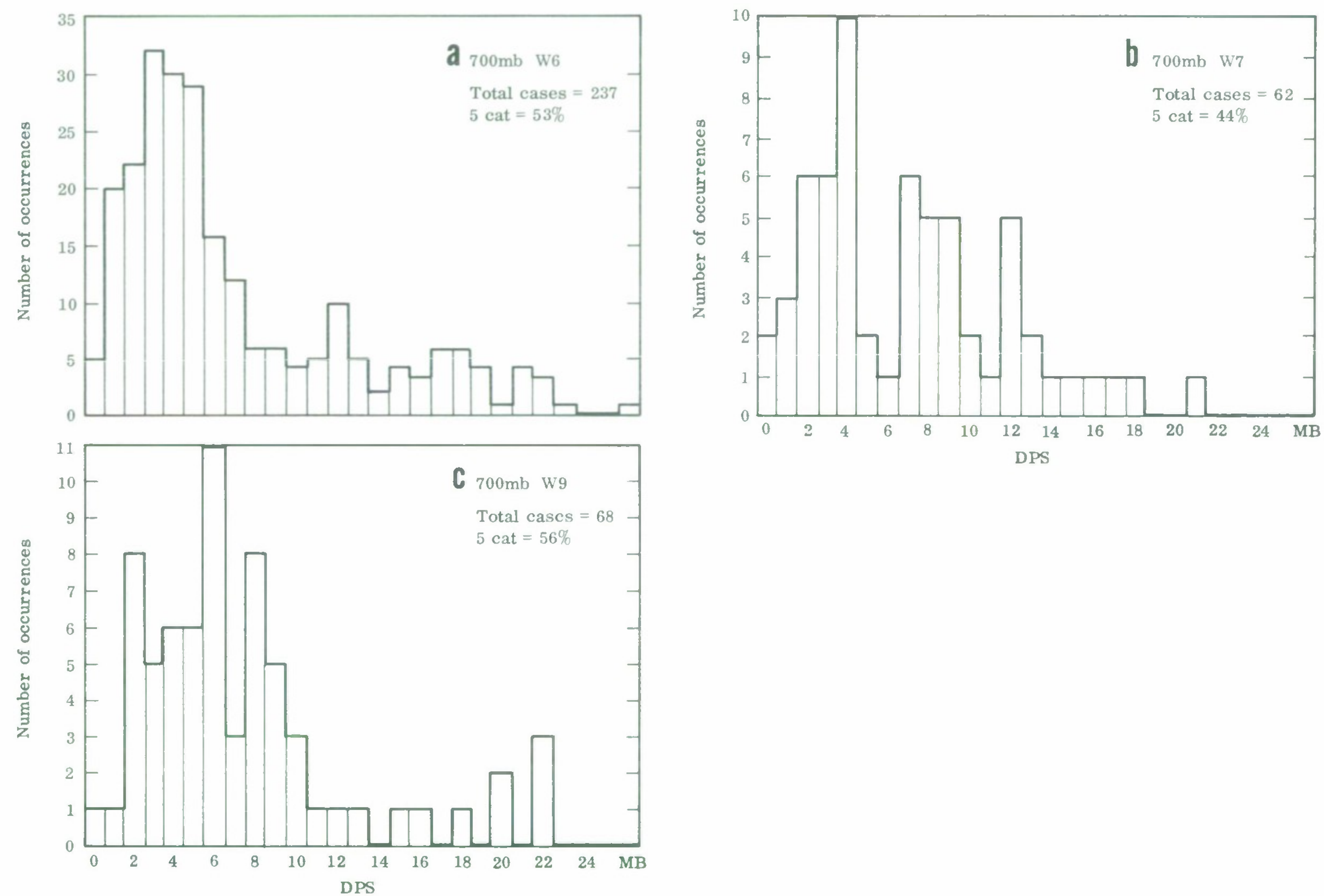


Fig. 14. Distribution of 700-mb dew-point spread for selected past-weather types.

At 700 mb, the first variable considered is total cloud amount. The overcast category of total cloud amount yielded an acceptable relation while the other categories did not. Although well-defined weather systems occur less frequently during the warm season, cloudiness resulting in overcast conditions is closely related to moist conditions at mid-tropospheric levels.

The second variable considered is the low cloud type. Two of the nine cloud types yielded acceptable relationships to the 700-mb DPS. They were type 7 (scud clouds associated with the extratropical cyclones) and type 9 (anvil-shaped cumulonimbus). Note that type 3 (cumulonimbus, not anvil-shaped) had been selected at 850 mb but was unacceptable at 700 mb.

The third variable considered is middle cloud type. Here, again, two of the nine types yielded adequate relations to the 700-mb DPS. They were type 1 (thin altostratus) and type 6 (low altocumulus formed by spreading out of cumulus).

The fourth variable considered is present weather. The selected types varied from light precipitation (for which a diagnosed value of 2°C is recommended) to observed lightning (with a diagnosed value of 6°C).

Finally, three types of past weather account for the last branch of the 700-mb decision tree. They were type 6 (rain), type 7 (snow), and type 9 (thunderstorms).

The part of the developmental sample remaining after all cases containing acceptable surface-observed variables had been removed was called the "residual sample".

Statistical estimates of the 700-mb DPS were derived from this residual sample using the REEP technique. The results are discussed in subsection 7.

As was the case at 850 mb, there are similarities and differences between the 700-mb decision trees developed for the warm and cold seasons. Four variables (ww, C_L, W, C_M) constitute the cold-season decision tree while the warm-season decision tree comprises these variables plus N_T. The order in which the variables are considered reflects the basic difference between summer and winter weather as was explained in the discussion concerning 850 mb. The recommended values of DPS in the cold season were either 2°C or 3°C while in the warm season they vary from 2°C to 6°C.

5. 500-mb Decision Tree

It had been found [2] in the development of the 500-mb cold-season decision tree that usable results could be achieved only by considering variables jointly (rather than individually as had been done at the lower levels, 850 and 700 mb). Preliminary examination of the full sample climatology and individual histograms indicated a similar approach would be necessary for the development of the warm-season 500-mb decision tree. Further, it was apparent from the climatology that estimates of both moist and dry conditions could be realized at 500 mb.

Thus it was necessary to establish threshold values for moist conditions and for dry conditions. For moist conditions the value was 45% or more cases within five consecutive 1°C DPS intervals, and for dry conditions, 60% or more cases in which the DPS was greater than or equal to 15°C. Note that the 500-mb climatology (Fig. 4) has a primary peak at 17°C due to the use of statistical values of DPS which varies from 27°C at a temperature of 20°C, to 10°C at a temperature of -40°C. Therefore, the climatology of DPS at 500 mb has been altered significantly, in this case, from about 15°C and drier.

There were several logical ways to consider the surface variables jointly to form subsamples that would separate the moist cases from the dry cases. Considerable experimentation with the cold-season data gave us combinations that yielded the best basis for stratification of the moist and dry cases [2]. Preliminary appraisal of the warm-season histograms indicated that similar combinations were appropriate.

Figure 15 is the recommended 500-mb decision tree. The left side of the figure shows the combinations of surface-observed variables used to stratify the data sample and the right side shows the variables which yielded satisfactory 500-mb DPS estimates. Table VIII gives more information about the selected variables and Figs. 16 through 18 are individual histograms of the selected variables.

To isolate cases representing moist conditions at 500 mb the occurrence of low-cloud type 7 or middle-cloud type 1, 2, or 7 was considered. In this subsample, a satisfactory association was realized between the total cloud amount being overcast and the 500-mb DPS.

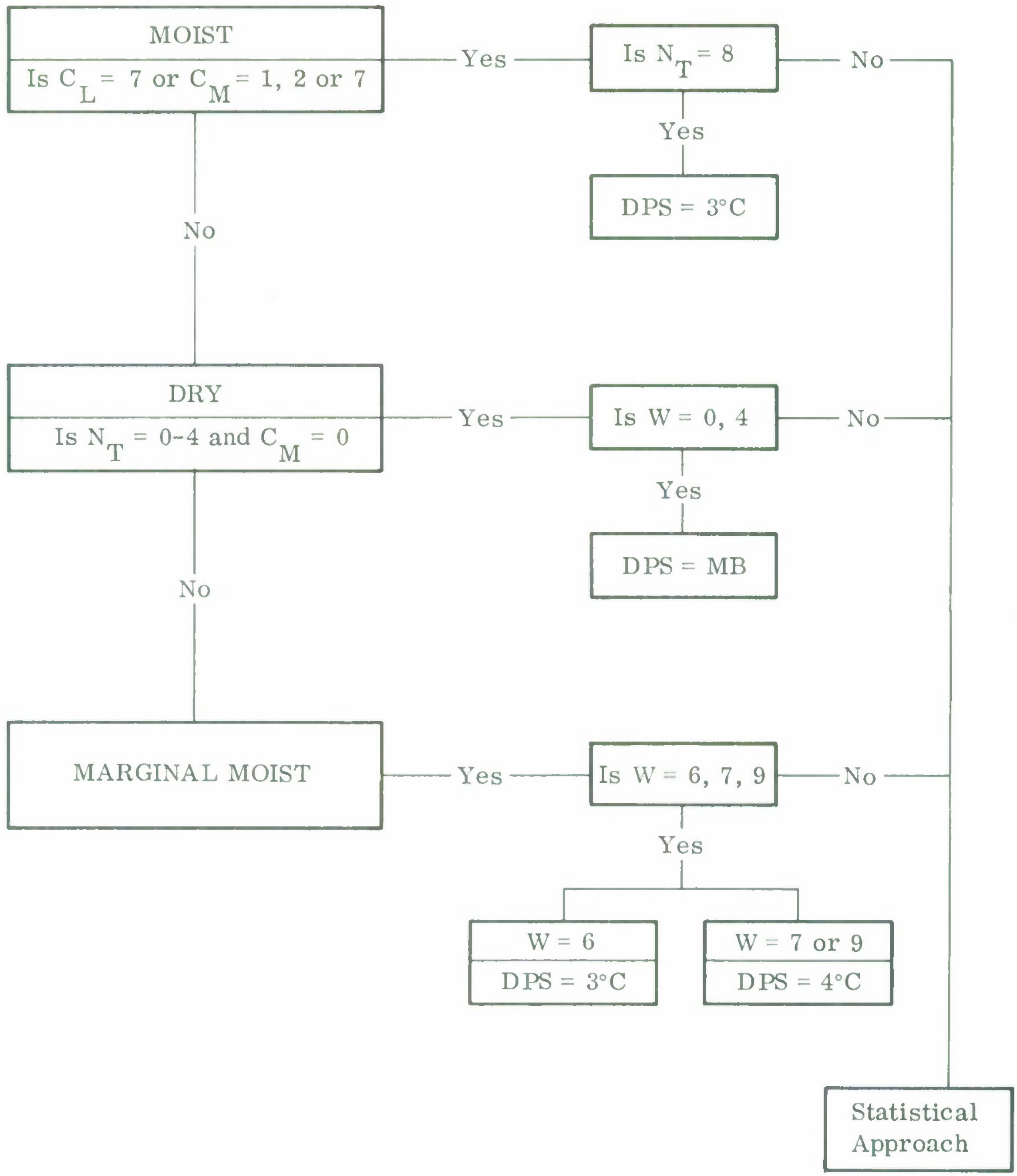


Fig. 15. 500-mb decision tree for warm season.

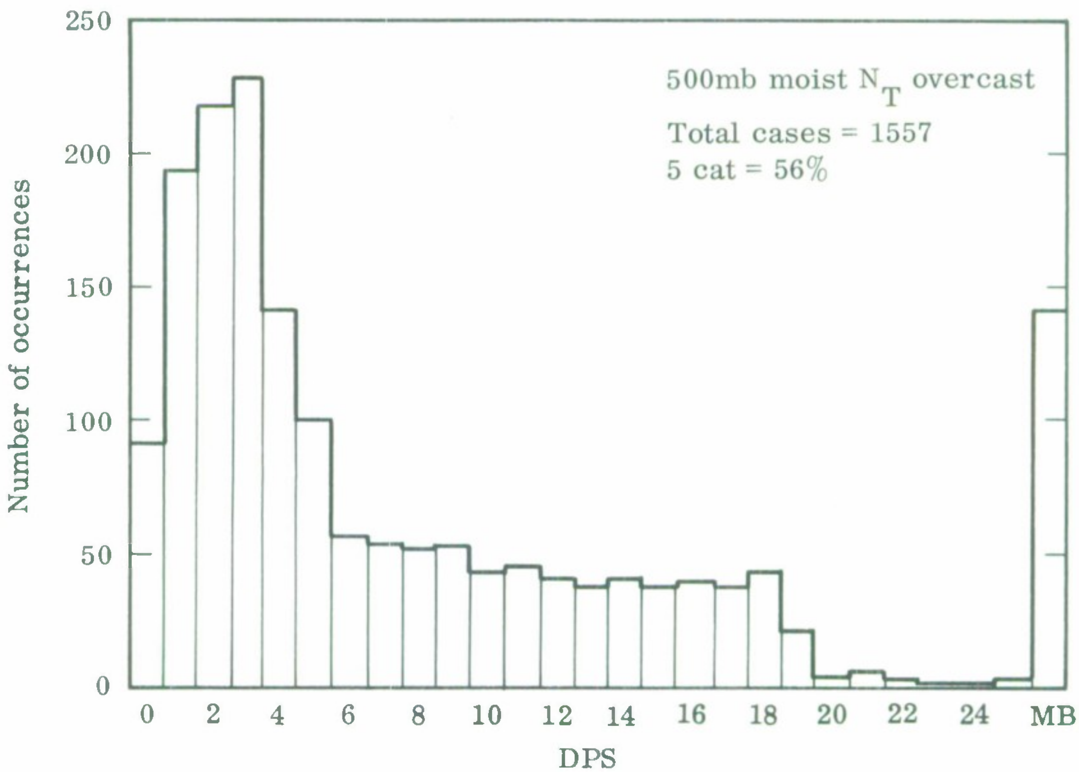


Fig. 16. Distribution of 500-mb dew-point spread for selected total-cloud amount types (moist subsample).

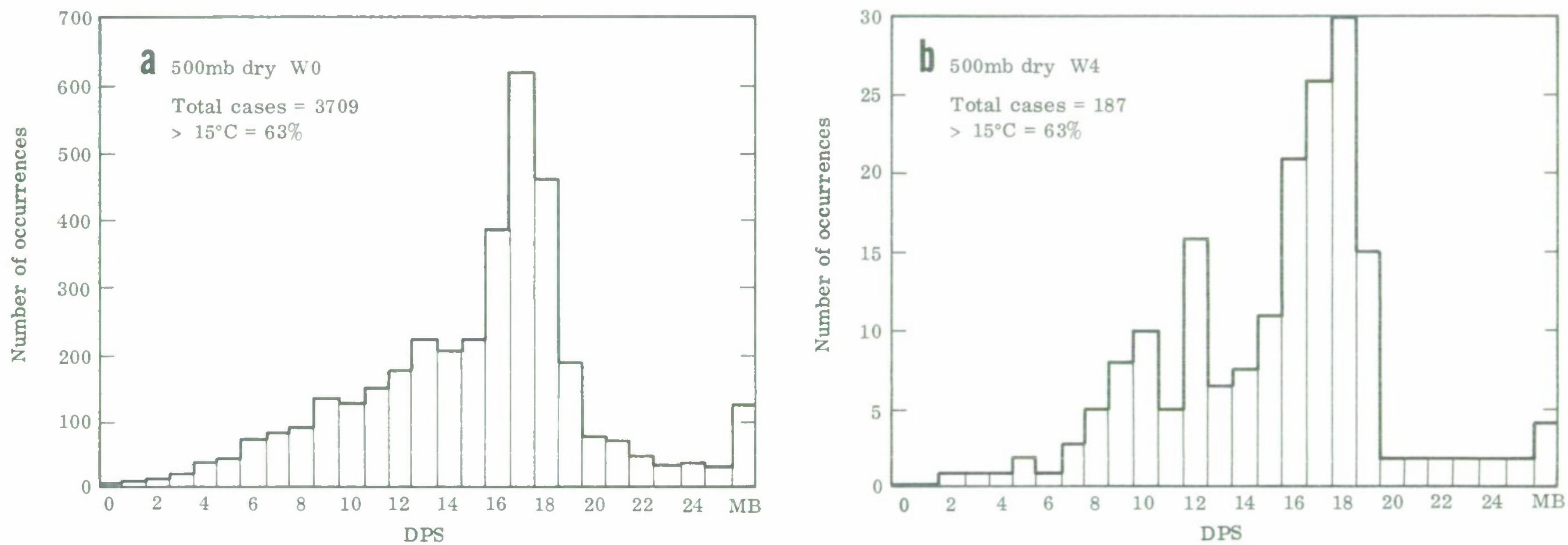


Fig. 17. Distribution of 500-mb dew-point spread for selected past-weather types (dry subsample).

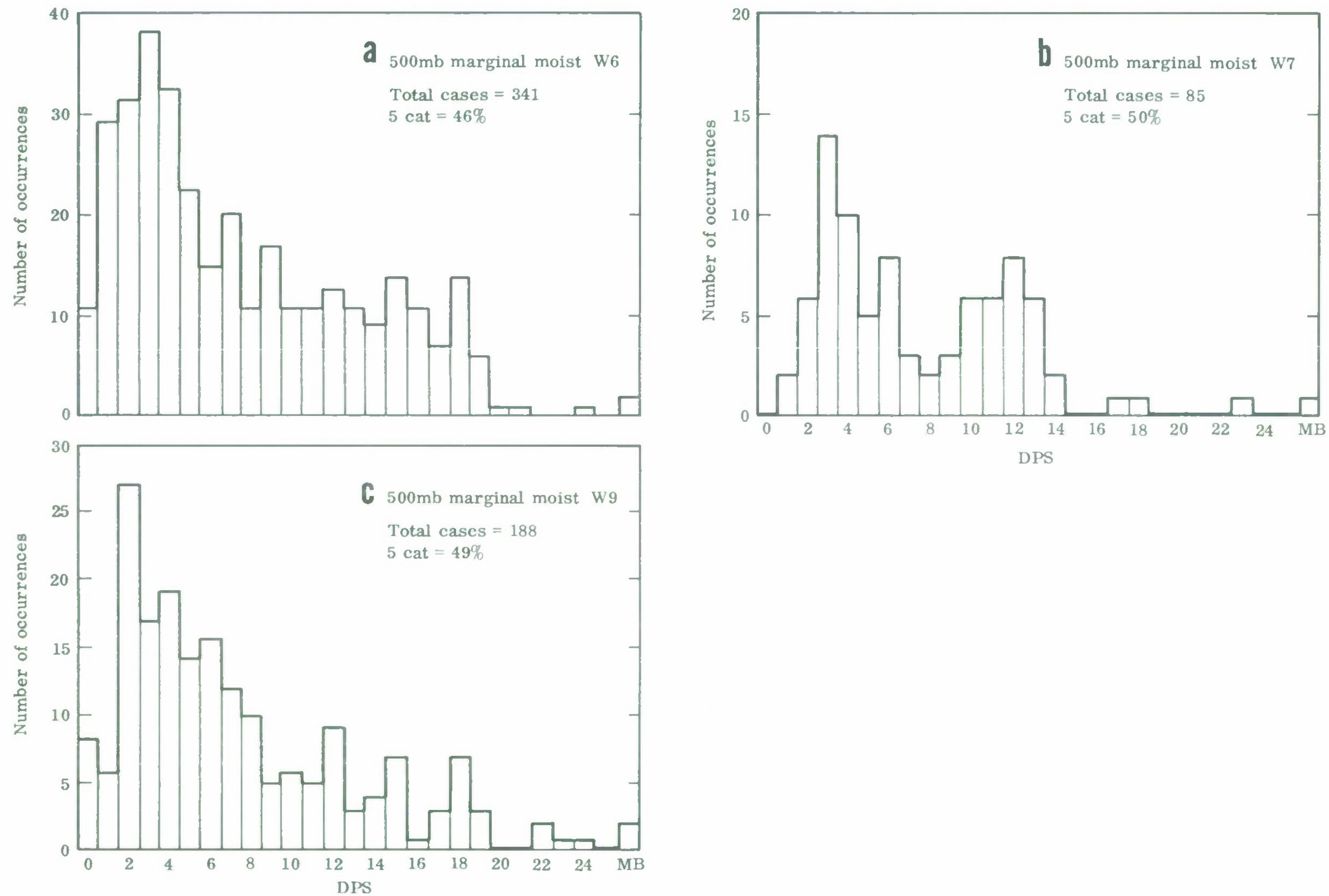


Fig. 18. Distribution of 500-mb dew-point spread for selected past-weather types (marginal-moist subsample).

TABLE VIII
SELECTED SURFACE VARIABLES
(500-mb)

Variable	Type	Modal DPS	Midpoint DPS	Five interval percent	Diagnoses
N_T (C_L=7 or C_M=1, 2, or 7) [moist]	8	3°C	3°C	56	1557
W (N_T=0—4 and C_M=0) [dry]	0	>15°C	>15°C	63*	3709
	4	>15°C	>15°C	63*	187
W [marginal moist]	6	3°C	3°C	46	341
	7	3°C	4°C	50	85
	9	2°C	4°C	49	188
				TOTAL	6067

*Percentage of cases where the 500-mb dew-point spread is greater than or equal to 15°C.

To isolate cases representing dry conditions at 500 mb the variables total cloud amount and middle-cloud type were considered jointly. In particular, the dry subsample was limited to those cases in which the total cloud amount was clear or scattered (N_T = 0—4) <u>and</u> there was not a reported middle-cloud type (C_M = 0). Within this subsample, two types of past weather (past 6 hr) yielded acceptable estimates of 500-mb DPS. They were type 0 (clear or few clouds) and type 4 (fog), both generally associated with widespread subsidence at levels below 500 mb.

The remaining subsample could not be satisfactorily stratified into marginal moist and marginal dry subsamples as had been done with the cold-season data. However, estimates of moist conditions were possible based on past weather from this subsample.

The three types of past weather selected were type 6 (rain), type 7 (snow), and type 9 (thunderstorms).

Having exhausted useful decision-tree diagnostic estimates from the 500-mb developmental sample, the remaining sample (residual sample) was set aside for the statistical evaluation, discussed in subsection 8.

The basic difference between the warm-season and cold-season decision trees developed for 500 mb is that the cold season was stratified into four subsamples and the warm season was stratified into three. Other differences concern the variable yielding an acceptable diagnosis within the dry subsample. In the warm-season decision tree described herein, past weather types 0 and 4 were used, while low-cloud type was used in the cold-season. Characteristics common to both are (a) the consideration of more than one variable at a time in developing the decision tree, and (b) the identical variables used to stratify the moist and dry subsamples for both seasons.

SECTION IV

STATISTICAL TECHNIQUE

The technique selected for the development of the diagonostic relations was the Regression Estimation of Event Probabilities (REEP) developed by Miller [10]. It was chosen because (a) it provides probability estimates of the several categories of the specificand (dew-point spread) and (b) the diagnostic relations developed by REEP can be used efficiently within an operational computer system where timing and storage usage considerations may be critical.

The procedure for the selection of specifiers in REEP is similar to that used in screening multiple discriminant analysis (MDA)[4]. MDA is a technique for selecting a minimum number of specifiers (from a large possible set) that most efficiently achieves discrimination among the groups of the specificand. For example, the specificand of dew-point spread had three groups. To select a minimum number of effective specifiers from a large set, a criterion, λ, is used to separate the effective from the ineffective specifiers. This criterion maximizes the distances between the mean values of the specificand groups and minimizes the spread of points about each of the group means. The criterion can be represented as a single number by computing the following ratio:

$$\lambda = \frac{\text{(Measure of distance between group means)}}{\text{(Measure of spread of points about each group mean)}} \tag{IV-1}$$

The λ-criterion is used as follows. Let there be P possible specifiers. The first step is to compute P values of λ, based on each specifier. The first specifier selected is the one that gives the largest λ. P-1 values of λ are computed using two specifiers, one of which is the first specifier selected and the other, one of the remaining P-1 specifiers. The one giving the maximum value of λ is selected as the second specifier. Third and higher specifiers are selected by computing λ using three and more specifiers. The procedure is continued until a statistical test indicates that the last specifier selected does not contribute significant discriminating information.

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[4]A complete description of MDA is given by Miller [9]. The brief explanation given here is adapted from Enger [8].

Given a set of specifiers (independent variables), $P_1, \ldots, P_r$, the problem then consists of estimating the probability distribution over a set of G mutually exclusive and exhaustive groups defined for the specificand. A series of multiple regressions are preformed on G zero-one dependent variables, $Y_1, \ldots, Y_G$, where each dependent variable is associated with one of the G specificand groups. The independent variables, $P_1, \ldots, P_r$, are identical in each of the G regressions. From the series of regressions, a least-square estimate of the A's in the following set of equations is obtained.

$$
\begin{aligned}
E(Y_1 X) &= A_{1s} P_s \\
E(Y_2 X) &= A_{2s} P_s \\
&\vdots \\
E(Y_G X) &= A_{Gs} P_s \qquad (P_0 = 1)
\end{aligned}
\tag{IV-2}
$$

All of the conditional distributions are Bernoulli (zero-one) distributions. For a single trial the expectation is equal to the probability that $Y_G = 1$. Therefore, the regression functions yield least-square estimates of the group probabilities. These extimates contain both desirable and undesirable features. The desirable properties are that the estimates add up to unity and that the estimates essentially minimize the Brier-Allen P score. An undesirable property is that the estimates are not bounded by 0 and 1. To overcome this problem, the estimates are renormalized by (a) setting all negative estimates equal to zero, (b) setting all estimates greater than one equal to one and (c) dividing each estimate by the overall sum.

The REEP procedure for selection of specifiers provides information, regarding the reduction of variance of the specificand, that is not available from most other statistical techniques. The reduction is stratified by the contribution to each category of the specificand. That is, when a selected specifier discriminates effectively between one category and the others, the reduction of the variance of that particular category is greater than that of the others. Similarly, other specifiers more effectively reduce the variance of other specificand categories.

The REEP technique was applied to each of the residual samples independently. The specificand (dew-point spread) was separated into 3 categories at each of the 3 levels. The range of values for the 3 categories and a value representative of the range are listed in Table IX.

TABLE IX
DEW-POINT SPREAD CATEGORIES FOR REEP EXPERIMENTS

Level (mb)	Category	Range of values (° C)	Representative value (° C)
850	1	$0 \le DPS \le 6$	3
	2	$6 < DPS \le 13$	10
	3	$13 < DPS$	18
700	1	$0 \le DPS \le 6$	3
	2	$6 < DPS \le 14$	11
	3	$14 < DPS$	19
500	1	$0 \le DPS \le 8$	4
	2	$8 < DPS \le 15$	12
	3	$15 < DPS$	20

6. 850-mb Residual Sample

The 850-mb REEP equations were developed from a residual sample consisting of 5400 cases in the dependent sample and 1386 cases in the independent sample. Approximately 20% of the residual sample was set aside as independent data.

The surface DPS categories describing dry and moist conditions were selected first and third as specifiers of the 850-mb DPS. These and the other surface variables selected as significant specifiers of 850-mb DPS are listed in Table X. Included are the category (dummy variable) of the surface variable which was selected and the coefficients associated with each selected specifier in the REEP equations for the 3 categories of the specificand. A positive coefficient increases the probability of the given category occurring while a negative coefficient decreases the probability.

TABLE X

850-mb SELECTED VARIABLES AND ASSOCIATED COEFFICIENTS

Order	Selected variables	Range of values	Coefficients of REEP equations		
			Cat. 1	Cat. 2	Cat. 3
1	DPS	$15 < DPS$	-.095	-.249	.344
2	h	9	-.206	.048	.159
3	DPS	$0 \leq DPS \leq 5$	.296	-.123	-.173
4	C_M	0	-.096	.030	.066
5	T	$20 < T \leq 30$	.081	-.020	-.061
6	DPS	$5 < DPS \leq 12$	.130	-.043	-.087
7	ww	$0 \leq ww \leq 1$	.082	-.016	-.066
8	N_T	$5 \leq N_T \leq 7$	.076	-.039	-.037
9	T_d	$10 < T_d \leq 20$	.058	-.031	-.027
10	T	$T \leq 0$	.085	.087	-.172
11	T_d	$-10 < T_d \leq 0$	-.030	-.071	.101
12	C_L	6	-.133	-.053	.186
Additive Constants			.283	.431	.286

Note that the first and third specifiers selected make the largest positive contributions to the probability of occurrence of the specificand categories 3 and 1 respectively.

Of the several other specifiers selected, noteworthy additional contributions to the categorical probabilities were made by the 2nd, 6th, 10th, and 12th specifiers. The 2nd specifier indicates by its occurrence (cloud base $\geq$ 8000 ft) a lower probability of Category 1 ($DPS \leq 6$) and a higher probability of Category 3 ($DPS > 13$). The increased likelihood of moist conditions at 850 mb, when the surface dew-point spread falls in the range $5 < DPS \leq 12$ (6th selected specifier), can be explained by adiabatic cooling and increased humidity with height typically present under a warm-season inversion. Thus, a surface DPS between 5 and 12°C would be associated with an 850-mb DPS most frequently in the range described by Category 1 of the specificand. The characteristics of the 10th specifier ($T \leq 0°$ C) could be attributed to small polar outbreaks in which considerable overrunning of the shallow air mass results in at least somewhat moist conditions at 850 mb. Finally, the high probability of dryness and low probability of moistness at 850 mb, where low-cloud type 6 (stratus) is present (12th selected specifier), is related to the lower base of the subsidence inversion generally associated with stratus.

Testing of the 850-mb REEP equations to diagnose 3 categories of 850-mb DPS was conducted with both the dependent and independent data samples (5400 and 1386 cases, respectively). The results were evaluated with contingency tables and are shown in Table XI.

TABLE XI
(Specification of 3 categories of DPS) 850-mb RESIDUAL SAMPLE

(a) Dependent-data specification of dew-point spread

		Observed			Total Specified
		1	2	3	
Specified	1	1254	700	342	2296
	2	533	910	708	2151
	3	53	244	656	953
Total observed		1840	1854	1706	5400
Number of hits		2820		Percent correct 52. 2	

(b) Independent-data specification of dew-point spread

		Observed			Total Specified
		1	2	3	
Specified	1	296	196	90	582
	2	140	258	209	607
	3	11	48	138	197
Total observed		447	502	437	1386
Number of hits		692		Percent correct 49. 9	

The equations tend to overspecify moist conditions and underspecify dry conditions in both the dependent and independent data samples. The percentages on independent data are slightly lower than those on the dependent data sample (49. 9% compared with 52. 2%). Because the diagnoses obtained with the REEP equations are of variable quality, their use in an operational system should be selective, as was recommended earlier [2]. That is, the diagnosed DPS should only be used if the probability of occurrence of a given category exceeds a minimum value (0.50 for example). Using the REEP equations in this manner will reduce the number of diagnoses retained but they will be of higher quality and will result in higher percent correct diagnoses scores than would be obtained by using the equations in every case.

7. 700-mb Residual Sample

The 700-mb REEP equations were developed from a residual sample comprising 6408 cases in the dependent sample and 1569 cases in the independent sample.

The categories of the surface-observed variables selected as significant specifiers of the 700-mb DPS are listed in Table XII. Also included are the coefficients of the 15 selected specifiers associated with the 3 categories of 700-mb dew-point spread.

TABLE XII

700-mb SELECTED VARIABLES AND ASSOCIATED COEFFICIENTS

Order	Selected variables	Range of values	Coefficients of REEP equations		
			Cat. 1	Cat. 2	Cat. 3
1	C_M	0	-.158	-.003	.161
2	W	0	-.121	.040	.081
3	DPS	$0 \le DPS \le 4$	.093	-.038	-.055
4	C_L	0	-.128	-.068	.195
5	P	$1020 < P$	-.153	.005	.148
6	T_d	$20 < T_d$	-.064	.112	-.048
7	DPS	$15 < DPS$	-.100	-.061	.160
8	h	$4 \le h \le 6$	-.093	-.063	.156
9	P	$1010 < P \le 1020$	-.086	.018	.068
10	W	$3 \le W \le 5$	-.127	.024	.103
11	W	8	.104	-.087	-.017
12	FF	$0 \le FF \le 3$	.033	.024	-.057
13	C_H	2	-.017	.079	-.061
14	N_T	$1 \le N_T \le 4$	-.043	.026	.016
15	C_H	$7 \le C_H \le 9$	-.110	.035	.075
Additive Constant			.578	.374	.048

The first two specifiers selected ($C_M = 0$ and $W = 0$) would, with their occurrence, reduce the probability of moist conditions and increase the probability of dry conditions at mid-tropospheric levels (700 mb). This trend is furthered by the 4th specifier (C_L=0) and 5th specifier (1020 < P). Looking at these four specifiers jointly, one can formulate a very logical synoptic situation for the warm season. Surface pressures in excess of 1020 mb are most frequently associated with the center of air masses which are predominantly dry above the subsidence inversion which often extends downward to the surface in the general area of the high pressure center. Thus, there is little or no cloudiness associated (C_L=C_M=0) for periods of several hours (W=0). Note that the contributions of the surface DPS categories (3rd and 7th specifiers) to the categorical probabilities are less than was the case at 850 mb — as one would expect. Of the 15 selected specifiers, only the past occurrence of showers (W=8) increases the probability of the moist category of 700-mb DPS by more than 10 percentage points. Looking at the list of selected variables, it is seen that the occurrence of most of them would indicate dry conditions at 700 mb. When most of these variables do <u>not</u> occur moist conditions would be the case because of the high additive constant for the moist category (0.578).

The REEP equations developed for the diagnosis of three categories of 700-mb DPS were tested on the dependent sample of 6408 cases and the independent sample of 1569 cases. The results are presented in Table XIII. The 700-mb equations yield scores slightly lower than at 850 mb and like the results at 850 mb were lower on independent data by a slight amount (47.9% compared with 50.7%). The 700-mb equations overspecify (more specified than observed) the dry category while they underspecify the middle category (6 < DPS ≤ 14). Here again, using the diagnoses in a selective manner (as suggested earlier [2]) based on the probability of occurrence will result in fewer, but more reliable, diagnoses.

8. 500-mb Residual Sample

The 500-mb REEP equations were developed from a residual sample of 5364 cases in the dependent sample and 1361 cases in the independent sample. Consistent with the other levels, data was set aside to test the 500-mb REEP equations.

TABLE XIII
700-mb RESIDUAL SAMPLE

(a) Dependent-data specification of dew-point spread

		Observed 1	Observed 2	Observed 3	Total Specified
Specified	1	682	417	267	1366
	2	280	552	372	1204
	3	518	1307	2013	3838
Total Observed		1480	2276	2652	6408
Number of Hits		3247		Percent Correct 50.7	

(b) Independent-data specification of dew-point spread

		Observed 1	Observed 2	Observed 3	Total Specified
Specified	1	134	110	62	306
	2	56	110	96	262
	3	129	364	508	1001
Total Observed		319	584	666	1569
Number of Hits		752		Percent Correct 47.9	

Table XIV lists the 15 selected specifiers with their regression coefficients for the 3 categories of 500-mb DPS.

Quite logically, the presence or absence of middle clouds ($C_M \neq 0$ or $C_M = 0$) is the best single discriminator between moist or dry conditions at 500 mb (and also at 700 mb). While categories of surface DPS were significant specifiers of 850 mb humidity and of lesser importance at 700 mb, they were not selected at all as specifiers of 500-mb DPS. Low-cloud types 3 and 9 (cumulonimbus clouds of considerable vertical extent) make almost identical contributions to the specificand categories, particularly the moist category. Also making a positive contribution to the moist category was the grouping of precipitation occurrences (excluding drizzle) ($59 \leq ww \leq 99$). The three surface temperature terms selected illustrate an interesting association between two seemingly unrelated variables.

TABLE XIV
500-mb SELECTED VARIABLES AND ASSOCIATED COEFFICIENTS

Order	Selected variables	Range of values	Coefficients of REEP equations		
			Cat. 1	Cat. 2	Cat. 3
1	C_M	0	-.142	.002	.140
2	N_T	$5 \leq N_T \leq 8$	.098	-.067	-.031
3	T_d	$10 < T_d \leq 20$	-.003	-.080	.084
4	C_L	9	.182	-.049	-.133
5	T	$20 < T \leq 30$	-.089	-.123	.212
6	T	$10 < T \leq 20$	-.062	-.082	.145
7	W	$0 \leq W \leq 1$	-.074	.027	.047
8	C_H	2	.076	.034	-.109
9	T	$30 < T$	-.170	-.133	.303
10	C_L	3	.180	-.082	-.098
11	h	9	.033	-.077	.044
12	ww	$59 \leq ww \leq 99$	.161	-.062	-.098
13	N_h	8	.052	-.142	.090
14	C_M	/	-.249	.089	.160
15	C_H	/	.149	-.020	-.129
Additive Constant			.392	.518	.090

These results clearly suggest that the higher the surface temperature, the drier the humidity will be at 500 mb (approximately 18,000 ft). Note that the probability of the dry category occurring increases more when the 9th specifier ($30 < T$) occurs than when the 5th ($20 < T \leq 30$) occurs, which in turn exceeds the contribution of the 6th term ($10 < T \leq 20$).

High surface temperatures will frequently occur in large tropical or sub-tropical high pressure air masses well removed from frontal boundaries and associated overrunning moisture. Further, these large air mass systems are frequently characterized by subsidence at high levels, accounting for the increased likelihood of dry conditions at 500 mb. Finally, the 14th and 15th specifiers warrant discussion. The occurrence of C_H = unknown when C_M is known suggests cloudy conditions at or near 500 mb and understandably results in an increased likelihood of moist conditions at 500 mb. However, when C_M is unknown there must exist a lower overcast; therefore, C_H must also be unknown. In assessing the contribution of C_M = unknown one must consider it jointly with C_H = unknown, in which case one finds a decreased probability of Category 1 (-.100) and increased probability of categories 2 and 3 (+.069 and +.021 respectively).

The 500-mb REEP equations were applied to the dependent and independent samples of 5364 and 1361 cases respectively. The results are presented in Table XV. Unlike the 850-and 700-mb equations, the REEP equations for 500-mb DPS diagnosis yield a distribution of diagnoses very similar to the observed distribution. Further, the results on independent data were slightly better than the dependent results (49.4% compared with 48.5%). It is suggested that the 500-mb REEP equations be used selectively as suggested for the other levels. Again, by doing this, there would be fewer diagnoses of higher quality.

TABLE XV
500-mb RESIDUAL SAMPLE

(a) Dependent-data specification of dew-point spread

		Observed			Total Specified
		1	2	3	
Specified	1	992	598	365	1955
	2	507	812	448	1767
	3	353	492	797	1642
Total Observed		1852	1902	1610	5364
Number of Hits		2601		Percent Correct 48.5	

(b) Independent-data specification of dew-point spread

		Observed			Total Specified
		1	2	3	
Specified	1	264	137	92	493
	2	127	177	113	417
	3	97	123	231	451
Total Observed		488	437	436	1361
Number of Hits		672		Percent Correct 49.4	

SECTION V

INDEPENDENT DATA TESTING AND RECOMMENDATIONS

In the original formulation of this study, the plan was to develop, by objective means, diagnostic relationships between surface-observed variables and the DPS at 850, 700, 500, and 400 mb for both the cold and the warm seasons of the year. Cold season relationships had been developed for the four levels and reported earlier [2]. Due to the nature of the upper-air data available for the development of warm season diagnostic relationships it was felt that satisfactory relationships could not be developed for 400 mb. The reasons for this are discussed in Section II. However, the requirement still existed for recommendations for means of diagnosing DPS at 400 mb during the warm season. The alternatives, from techniques available, would be (a) apply the 400-mb decision tree developed for the cold season to all months of the year, or (b) apply the 500-mb decision tree developed for the warm season to both the 500- and 400-mb levels during the warm months of the year.

Teletype data for the period of June, July and the first part of August, 1965 were processed and evaluated to determine the better procedure. Approximately 25 U. S. stations routinely reporting surface-synoptic and upper-air data twice-daily were used for the evaluation.

Decision-tree diagnoses were obtained from the warm-season 500-mb decision tree and compared with the observed 400-mb DPS. Similarly, the cold-season 400-mb decision tree diagnoses were obtained and compared with the observed 400-mb DPS. The results for the two and a half month sample are summarized in Table XVI. Diagnoses made with both of these decision trees are classified either moist or dry while the observations have been tabulated in three categories; moist (0—5° C), marginal (6°—14° C), and dry (>14° C).

Comparing the diagnoses made by the two decision trees, one finds little difference. The 400-mb cold-season decision tree yields slightly more reliable diagnoses (having a precent correct score 2. 2 percentage points higher) but the 500-mb warm-season decision tree yields more diagnoses of comparable quality

TABLE XVI

COMPARISON OF TWO METHODS FOR DIAGNOSING 400-mb DEW-POINT SPREAD

(a) Warm-season 500-mb decision tree

		Observed			Total Diagnosed
		Moist	Marginal	Dry	
Diagnosed	Moist	$\boxed{134}$	191	82	407
	Dry	2	174	$\boxed{452}$	628
Total observed		136	365	534	1035
Hits = 586; % correct = 56.6					

(b) Cold-season 400-mb decision tree

		Observed			Total Diagnosed
		Moist	Marginal	Dry	
Diagnosed	Moist	$\boxed{100}$	143	56	299
	Dry	5	176	$\boxed{443}$	624
Total observed		105	319	499	923
Hits = 543; % correct = 58.8					

$\boxed{}$ Denotes correct diagnoses (hits)

(1035 diagnoses compared to 923). The judgement concerning the decision tree to be used to diagnose 400-mb DPS for the warm season reduces to operational considerations exclusively since there is no justifiable meteorological reason for choosing one or the other.

A second problem that was investigated concerned the justification of developing relationships for separate seasons (cold and warm). For example, does the warm-season 500-mb decision tree yield more and better diagnostic estimates of the 500-mb DPS than the cold-season 500-mb decision tree during the summer months? The warm-season 500-mb decision tree diagnoses were compared with the observed 500-mb DPS and evaluated against the cold-season 500-mb decision tree diagnoses also compared with the 500-mb DPS. Table XVII summarizes the results of this comparison conducted with the two and a half months of observations. Here again, the diagnoses are classified as moist or dry and the observations as moist, marginal, and dry.

TABLE XVII
COMPARISON OF TWO METHODS FOR DIAGNOSING
500-mb DEW-POINT SPREAD

(a) Warm-season 500-mb decision tree

		Observed			Total Diagnosed
		Moist	Marginal	Dry	
Diagnosed	Moist	$\boxed{178}$	157	72	407
	Dry	2	151	$\boxed{475}$	628
Total observed		180	308	547	1035
Hits = 653; % correct = 63. 1					

(b) Cold-season 500-mb decision tree

		Observed			Total Diagnosed
		Moist	Marginal	Dry	
Diagnosed	Moist	$\boxed{125}$	95	35	255
	Dry	5	128	$\boxed{340}$	473
Total observed		130	223	375	728
Hits = 465; % correct = 63. 9					

$\boxed{}$ Denotes correct diagnoses (hits)

The difference in percent correct scores realized by the two decision trees is negligible. However, the warm-season decision tree yielded over 300 more diagnoses of the 500-mb DPS than did the cold-season decision tree.

Comparative contingency tables were also obtained separately for June, July and August data. In all months, a greater number of diagnoses were obtained using the warm-season decision tree. In July and August the percent correct scores were also higher but this was not the case in June. This result is interesting in view of the fact that the warm-season decision tree was developed from data largely limited to the months of September and October. The above result may suggest that the warm-season decision trees should be used in the months from July through October or November, with the cold-season trees being employed for the remainder of the year. More extensive comparative testing with independent data is required to fully support the above tentative conclusion.

The reason for developing reliable diagnostic estimates of DPS was to increase the areal distribution of humidity information for input to an objective technique for analyzing humidity. Therefore, it is recommended that the warm-season 500-mb decision tree be used during the warmer months of the year since it would generate more diagnoses per map time. Time did not permit a similar comparison at 850 and 700 mb. However, since there are unique differences justified by meteorological reasoning between the warm-season and cold-season decision trees developed for these two levels, it is recommended that the decision trees at 850 and 700 mb developed from warm-season data be used during the warm season and those developed from cold-season data be used during the cold season. As explained earlier, the decision concerning which decision tree to use to diagnose 400-mb dew-point spread during the summer season must be made from operational considerations.

SECTION VI

HUMIDITY DIAGNOSIS AND ANALYSIS TECHNIQUE

The preceding three sections discuss the development and testing of the diagnostic relationships for the warm season of the year. The following sections present the results of experiments in which diagnostic data obtained from the cold-season relationships [2] were used for analyses of DPS.

The data processing required for this phase of the study was discussed generally in Section II and shown in a flow chart (Fig. 3). This section discusses in detail the logic that was required for this data processing and the developmental testing described later. The first three processing procedures perform data processing and computations on the three basic sets of data (surface, upper-air and CPS). The fourth and fifth combine and analyze these data in various ways.

Surface-synoptic station data in the European area (see Fig. 2) were extracted for the time period 00Z Feb 6 — 12Z Feb 16, 1962 (22 observation times). The required surface data were unpacked and checked to determine if any of the variables to be used in the diagnostic relationships were missing.

9. Humidity Diagnostic Procedure

The humidity diagnostic procedure generates diagnostic estimates of the DPS at 850, 700, and 500 mb. The procedure is generally as follows. First the cold-season decision trees developed for the three levels [2] are applied to the surface observations at each station within the developmental analysis area. Second, if a decision-tree estimate can not be obtained for a given level, the REEP equation applicable to that level [2] is then applied to the surface observation, yielding probabilities for the three categories of DPS at the given level. These probabilities are examined for an "occurrence" diagnosis; i. e., the probability of occurrence for a given category must equal or exceed a specified value (usually 0. 50). In the absence of "occurrence" diagnoses, the probabilities are examined for "non-occurrence" diagnoses in which the probability of a category must be less than or equal to another specified value (usually 0.10).[5] For each case in which a decision-tree or REEP diagnosis is made, the following information is saved for later use: station name and location, the diagnosed DPS, and its probability of occurrence (if the DPS is a REEP diagnosis). The probability of occurrence is obtained from the REEP equation, if used; if a decision-tree diagnosis was made, an indicator of 1.0 is used. This procedure required options that would govern the levels to be processed and the types of diagnostic estimates to be attempted for any given experiment: that is, one experiment might consider only decision-tree diagnoses while another might consider decision-tree and REEP "occurrence" diagnoses only.

Applying the decision trees and three-category REEP equations requires certain assumptions; i. e., in the 500-mb decision tree a DPS value of 20° C is used for cases in which "motorboating" is diagnosed. The diagnosed value of DPS used for non-motorboating branches of the 500-mb decision tree and for the 850- and 700-mb decision trees were those suggested in [2]. Further assumptions in the application of REEP equations are summarized in Table XVIII. The three categories of DPS represent a range of values having categorical limits, as defined in Table XVIII, but a single numerical value must be used to represent the categories when a diagnosis is made. Table XVIII includes two values for each category; one used when an "occurrence" diagnosis is made and the other used when a "non-occurrence" diagnosis is made. A limiting value of DPS is assigned to categories 1 and 3. For example, at the 700-mb level, if category 1 is diagnosed to not occur, the limiting value indicates that the DPS is diagnosed to be at least 7° C. Since a non-occurrence diagnosis of category 2 does not give specific information about DPS, non-occurrence diagnoses are not made for this category. It should be remembered that an occurrence or non-occurrence diagnosis is made only if a decision-tree diagnosis is not possible. The specified probability to be used for the acceptance of "occurrence" or "non-occurrence" diagnoses is also included. Finally, the REEP equation can be applied only if all the surface variables included in the equation are present in the

[5] Such a category would, therefore, have a high probability of not occurring.

TABLE XVIII

SUMMARY OF INFORMATION REQUIRED FOR THE USE OF REEP EQUATIONS

Level (mb)	Category limits (° C)	Surface variables required	Diagnosed DPS (° C)		Normal critical probability	
			Occurrence value	Non-occurrence limiting value	Occurrence (≥ 0.50)	Non-occurrence (≤ 0.10)
850	$0 \leq DPS \leq 5$	T, T_d, ww	3	6	.5	.1
	$5 < DPS \leq 10$	N_T, h, C_L	8	—	.5	—
	$10 < DPS$	app	13	10	.5	.1
700	$0 \leq DPS \leq 6$	T, T_d, ww	3	7	.5	.1
	$6 < DPS \leq 14$	C_L, C_M, C_H	11	—	.5	—
	$14 < DPS$	W, P, N_T	17	14	.5	.1
500	$0 \leq DPS \leq 7$	T, T_d, ww	4	8	.5	.1
	$7 < DPS \leq 16$	C_M, C_H, W	12	—	.5	—
	$16 < DPS$	P, FF, app	19	16	.5	.1

surface observation. The specific variables needed for the cold-season REEP equations are also listed in this table.

10. Radiosonde Extraction and Error Checking

The radiosonde data at stations in the developmental area were extracted. The DPS is computed at the 850-, 700-, and 500-mb levels from the temperature and dew-point observations. When the temperature and height are reported and the dew point is missing, motorboating is assumed and a DPS value of 20° C is inserted if the temperature is greater than -40° C. At each level, each station report of DPS is compared with an average value of DPS computed at a minimum of 8 stations in the vicinity. The error-checking procedure[6] requires that the difference between the DPS value being checked and the average DPS [11] be no more than 15° C. If the station report does not satisfy that requirement it is discarded. In this manner erroneous or unrepresentative DPS values are eliminated. Table XIX lists the total number of radiosonde reports available at each level within the area used in the developmental testing after error checking was completed for each time period of the data sample. The number of station reports that were eliminated because of missing or erroneous data was low. In an average observation time about 2 stations were eliminated because the temperature was missing or the computed DPS was negative. Additionally, about 2 stations were discarded because the DPS did not satisfy the error checking requirement of 15° C. The average number of RAOBS accepted by this program was 61 at 850 mb and 63 at the two higher levels.

11. Humidity Preprocessing

Radiosonde and diagnostic DPS data are merged and processed. Data at each level (850, 700 or 500 mb) are processed separately. The processing of the radiosonde and diagnostic data will be discussed separately in the following paragraphs. The procedure utilizes features of an earlier preprocessing procedure designed by Thomasell and Welsh [13] .

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[6]Original specifications by Frederick P. Ostby, Jr.

TABLE XIX
NUMBER OF RADIOSONDE OBSERVATIONS AVAILABLE AFTER ERROR CHECKING

Date (February)	Time (Z)	Level (mb)		
		850	700	500
6	00 12	60 69	64 71	64 72
7	00 12	49 38	52 39	51 39
8	00 12	71 69	71 72	71 73
9	00 12	52 42	56 44	56 43
10	00 12	72 67	78 67	76 70
11	00 12	67 68	70 70	72 68
12	00 12	59 56	62 61	61 58
13	00 12	61 65	65 68	66 69
14	00 12	72 61	76 63	72 61
15	00 12	60 57	60 57	59 55
16	00 12	65 62	69 65	69 65

In the processing of the radiosonde data the first step is to withhold a portion (controled by input) of the data from further processing. By withholding varying percentages of the radiosonde data, one can simulate regions where data are less dense.

The density of station reports about each grid point is then computed (i.e., a count is made of the number of reporting stations in a fixed area about each grid point). A station density is computed for all stations by performing a curvilinear interpolation using the densities at the four grid points surrounding each station.

For each radiosonde station processed, the following is output: station name and location, radiosonde observation indicator, station density, and DPS.

In processing the diagnostic data, the first step is to eliminate a given percentage of the diagnoses to stimulate the required data density to be used in the analysis. In addition, those stations at the same location as the radiosonde stations are not used.

The diagnostic probability listed with all diagnoses to be processed is examined next. All station reports having a probability greater than an input critical probability are selected and grouped in an occurrence diagnostic list. Those reports having a probability less than a second critical probability are selected for a non-occurrence diagnostic list. The two critical probabilities can vary and, therefore, the minimum reliability of the diagnostic data that is processed can also vary.

The density of station reports in the region about each processed occurrence diagnosis is computed in a procedure similar to that used for the radiosonde stations. The diagnostic station density includes both radiosonde stations and stations containing diagnosed DPS.

The occurrence-diagnostic and radiosonde data are grouped together with the following information being generated: station name and location, reliability indicator (REEP probability or indication as to whether DPS value is obtained from a radiosonde observation or decision tree), station density and DPS. The non-occurrence diagnostic data are generated separately and contain the same information except that there is no station density.

12. CPS Extraction and Conversion

CPS grid-point data are extracted for the required analysis area and observation times. The grid field is reordered to be consistent with other data and the CPS values are converted to approximate values of DPS by multiplying by the constants given in Table XX.

TABLE XX
CONSTANTS USED TO CONVERT CPS TO DPS*

Level (mb)	850	700	500
Constant	- 1/12.2	- 1/10.0	- 1/7.6

*Supplied by USAF Air Weather Service

The grid-point fields of DPS can then be used as an initial guess for the DPS successive approximation technique (SAT) analysis. On option, these fields may be modified with non-occurrence diagnostic data prior to analysis. The details of this procedure are discussed in the next section.

13. SAT Humidity Analysis

Prior to performing a successive approximation technique (SAT) analysis of DPS, an initial-guess field must be obtained. The initial guess consists of values of DPS at all grid points in the analysis area (the grid spacing used is that of the NWP grid) and serves as a first approximation of the DPS distribution. The initial guess may be obtained from CPS and (on option) non-occurrence diagnostic data. A SAT analysis is then performed in the anlaysis area using analysis stations (occurrence-diagnostic data and radiosonde stations not withheld). In this analysis, successive corrections are made to the initial-guess values at the grid points based on station reports within a radius of influence of the grid point. The extent of the correction made is a function of (a) the difference between the station value of DPS and the value obtained at the station location by interpolating from the 4 surrounding grid points, (b) the distance of the station from the corrected grid point and (c) the reliability of the station data. The SAT analysis technique was developed at the

Joint Numerical Weather Prediction Unit at Suitland, Md. [3] and adopted at TRC [4] and [13] as a basic analysis technique for various meteorological parameters. A more detailed description of the SAT analysis technique and its application to the analysis of DPS is given in the following paragraphs.

The initial guess to be used in the analysis can be obtained by three techniques: (a) initial-guess dew-point spread (IGDPS) data (obtained from CPS field) unmodified (b) IGDPS data modified by non-occurrence diagnostic information and (c) averaging observations about a grid point. In the third technique, the initial-guess value assigned to each grid point consists of the average DPS found at the stations closest to the grid point. This technique provides a suitable initial guess in regions where data are not sparse. It is, however, obviously not suitable for large oceanic regions of the Northern Hemisphere where radiosonde stations may be many hundreds of miles apart.

In the first and second techniques, the 12-hr forecasts of CPS which have been converted to DPS are utilized for the initial guess. The IGDPS data are unmodified in the first technique. In the second technique these data are modified with non-occurrence diagnostic information. If a non-occurrence diagnosis is found within an area (the size of which is specified by input) centered at a grid point, the grid-point value of DPS is checked to see if it is within the range of the category diagnosed not to occur. If the value is within the limits of this category, it is adjusted to exceed the upper limit (category 1 non-occurrence diagnosis) or be less than the lower limit (category 3 non-occurrence diagnosis) of the category diagnosed not to occur.

After the initial-guess field has been established by one of the above techniques, a successive approximation technique (SAT) analysis is performed. Much of the following description of the SAT analysis is taken from Davis [5]. For each analysis station (including diagnostic stations, when used), an interpolated value of the initial-guess field DPS is computed at the station location by fitting a curvilinear surface to the four surrounding grid points.

The interpolation equation is

$$S_{i,j} = \phi_1 + r\Delta i + S\Delta j + t\Delta i\Delta j, \qquad \text{(VI-1)}$$

where S_{ij} is the interpolated value of DPS at a station (i, j) and $r = \phi_2 - \phi_1$, $S = \phi_4 - \phi_1$ and $t = \phi_1 - \phi_2 + \phi_3 - \phi_4$. The values of ϕ are the initial-guess values of DPS and Δi and Δj are component distances to the analysis station as shown in Fig. 19.

After the interpolation has been performed, the interpolated value S_{ij} of DPS is compared with the station value ϕ_{STA} of DPS and the differenee is computed as

$$e_{ij} = \phi_{STA} - S_{i,j}. \qquad \text{(VI-2)}$$

The magnitude of $e_{i,j}$ refleets the error in the initial guess at the station location. The error differences at all stations within a radius R of the grid point are used to correct the initial-guess value at the grid point. The corrections are computed by the equation.

$$C_{i,j} = n^{-1} \sum RWM \cdot W \cdot e_{i,j}, \qquad \text{(VI-3)}$$

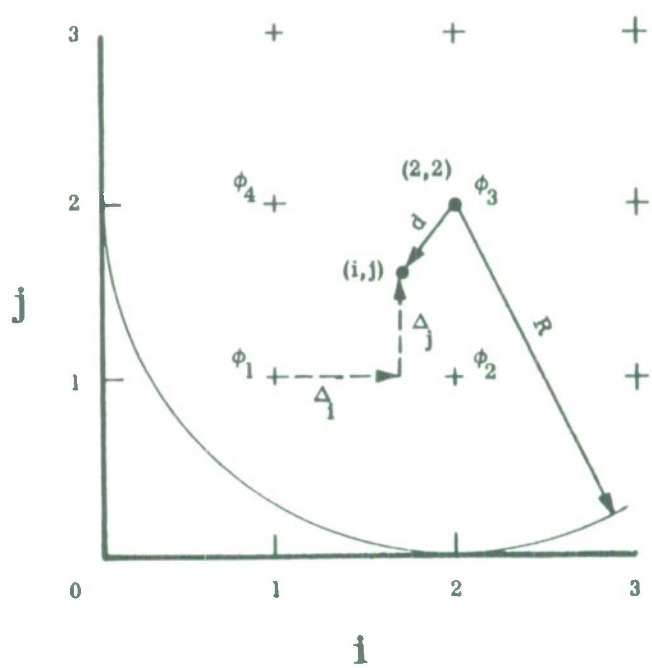

Fig. 19. Values required for computing a SAT correction for grid point (2, 2) from Davis (4).

where n is the number of stations for which errors can be computed within a radius R, and W is a weighting function for each station

$$W = \frac{R^2 - d^2}{R^2 + d^2} \qquad \text{(VI-4)}$$

with R the radius of search about the grid point and d the distance of the station from the grid point. The RWM term of Eq. (VI-3) is a relative weighting matrix correction and is applied to each station. The RWM correction is bounded by >0 and 1. The value to be used for a particular station report is determined by the station density (ρ) and the reliability (RI) of the data. The values of RWM to use in the analysis are supplied by input from a ρ x RI matrix. A further discussion of this term is given in the description of the results of the developmental testing found in the next section.

The value of C_{ij} computed from Eq. (VI-3) is added to the original value of DPS at the grid point. This procedure is applied to all grid points in the analysis area. For the first pass, the initial guess is corrected. The basic procedure of interpolating, obtaining errors, and making corrections is repeated for the number of passes specified by input. Normally, the magnitude of R is reduced for each succeeding pass. Smoothing and verification are possible between passes and after the final pass.

SECTION VII

TESTING THE HUMIDITY ANALYSIS TECHNIQUE

The developmental testing of the humidity analysis technique (Section VI) was conducted primarily to answer the following three basic questions:

(a) When should humidity diagnostic data be introduced into an objective analysis for which RAOB data are also available?

(b) How should the diagnostic data be incorporated into the analysis?

(c) What are the effects on the analysis of introducing the diagnostic data?

The first question is concerned both with the density of RAOB data available and with the reliability of the diagnostic information. The second question is answered by determining the relative weight to be given to the diagnostic data as well as by examining certain features of the SAT analysis procedure, such as the number of passes to make in the analysis, the size of the search radii to use, and the degree of smoothing to employ. The testing was largely concerned with weighting the diagnostic data. The third question is concerned not only with whether an improvement in the analysis can be noted by examining verification statistics, but also with any changes in the analysis characteristics (for example, the use of diagnostic data may lower or raise the humidity content as analyzed at grid points and may also modify the scale of the features of the humidity field that are included in the analyses).

14. Verification Procedures

The test analysis and verification areas are shown in Fig. 2. The two types of statistics are:

(a) Root-mean-square (rms) error at grid points and,

(b) contingency table verification of categories of DPS at grid points.

These statistics are available for the initial guess and after each pass of every map. Overall statistics are also given for all 22 observation times.

The rms error and contingency table statistics at grid points, for a given experiment, were obtained by comparing the analyzed DPS values at each grid point in the verification area with the verification dew-point spread analysis that was obtained from a previous analysis using all available RAOBS. Since the density of RAOBS in Europe is extremely high, the verification analysis gives a highly reliable representation of the moisture field. The verification area was reduced from the borders of the analysis by one NWP grid unit to eliminate any possible distortions in the analysis which might occur on the edge of the analysis area.

15. Data Characteristics

Table XXI gives, for each level, the total number of RAOBS for all 22 observation times having a DPS in an indicated range. The values of DPS shown in Table XXI represent the upper limit (except the seventh category, DPS $\geq$ 22). Note that very moist conditions prevailed through much of the period at the 850-mb level (over half the stations reported a DPS of less than 4° C) while moisture conditions varied at 700 and 500 mb.

TABLE XXI
DPS FREQUENCY FOR DEVELOPMENTAL SAMPLE

Level (mb)	Category limit (° C)							Total
	< 2	< 4	< 7	<11	<16	<22	≥22	
850	517	303	250	120	82	66	4	1342
700	333	231	270	220	176	150	19	1399
500	156	294	297	268	164	204	13	1396

The average number of decision-tree and REEP diagnoses at each observation time, for the three levels, is shown in Table XXII. The table shows the average number of stations processed per hour, for the 22 observation times, and the average number of diagnoses made per observation time. To simulate regions of varying data densities, only a fraction of the radiosonde and diagnostic data is used in the analysis.

TABLE XXII
AVERAGE NUMBER OF DIAGNOSES PER OBSERVATION TIME

Level (mb)	Stations processed	Decision tree	REEP occurrence	REEP non-occurrence
850	356	252	25	11
700	356	154	56	24
500	356	125	32	12

Decision-tree diagnoses completely predominate at the 850-mb level (in fact, they are made at about 70 percent of the stations processed). At 700 and 500 mb, the number of REEP diagnoses is somewhat larger, and because there are much fewer decision-tree diagnoses at these levels, the relative importance of the REEP diagnoses is increased.

Table XXIII shows moisture characteristics (moist versus dry) of the two types of diagnostic information at the three levels. The characteristics and frequency of diagnostic data will strongly affect the analysis. Some of the effects of the material contained in these three tables will be seen in Subsection 18, Results.

TABLE XXIII
MOISTURE CHARACTERISTICS OF DIAGNOSTIC DATA

Level (mb)	Decision tree	REEP
850	Moist only	Dry and Moist
700	Moist only	Moist and Dry
500	Moist predominately	Dry predominately

16. Data Density Simulation

Because the basic purpose of the analysis testing was to evaluate the results of humidity diagnoses in data-sparse regions, procedures were formulated to simulate data densities characteristic of these regions. The simulation of data-sparse regions is somewhat complicated by the fact that, although RAOBS are reported by approximately 100 stations in the test area at least once during the 22-observation time interval of the test period, the average number of RAOBS reported for any one observation time is about 65. Withheld station lists of 90, 75 and 50 stations were systematically compiled from the 100 possible stations. The number of RAOB stations withheld approximates the percentage of radiosonde stations withheld from the analysis. Table XXIV gives the approximate percentage of radiosonde and diagnostic data used in the low, medium, and high data-density simulations. Figures 20 and 21 show the distribution of stations reporting 700-mb DPS for low and medium data densities at 00Z, Feb. 11, 1962. The distribution changes with each observation time. An average of 6 RAOBS per observation time were included in the analysis for the sparse (low) data density simulation; averages of 16 and 31 were included in analyses for intermediate (medium) and dense (high) data-density simulations, respectively. Because the test area is approximately the size of the United States, it is felt that these density types are representative for the Northern Hemisphere. More surface station data than upper-air data were included in the simulation to better represent the data-sparse regions, such as the many ocean areas, in which there are a large number of ships reporting surface-synoptic data, while very few upper-air soundings are taken.

TABLE XXIV
INFORMATION AVAILABLE FOR DATA-DENSITY
SIMULATION EXPERIMENTS

Data-density type	Percentage of RAOB data	Percentage of diagnostic data
Low	10	20
Medium	25	33
High	50	Not used

17. Experimental Design

The principle factors listed below were given careful consideration.

(a) Level The relative frequency of moist and dry observations and diagnoses are considerably different at the three levels (see Subsection 15). Thus the impact of the diagnostic data will vary accordingly.

Fig. 20. Distribution of RAOBS at 700 mb on February 11, 1962 for low-data-density simulation (10% of RAOBS used).

Fig. 21. Distribution of RAOBS at 700 mb on February 11, 1962 for medium-data-density simulation (25% of RAOBS used).

(b) Data Density The extent of diagnostic data available and the relative weight to give the diagnoses is a function of the density region being simulated and the variations of data densities within the test area.

(c) Initial Guess and Test Area The first-guess field used in the present GWC humidity analysis (prior to modification) consists of the converted 12-hr CPS trajectory forecasts (called IGDPS in this report). In most of the experiments conducted, therefore, the IGDPS field was used as the initial guess. However, the quality of this initial guess can vary significantly within the test area. Because most of the IGDPS values in the western portion of the test area (Western Europe) are derived from trajectories that originated over the Atlantic Ocean, this portion of the field is expected to contain larger errors. That this was indeed the case will be seen in the results. Therefore, some experiments were performed using data within the western half of the analysis area only. In other experimentation the IGDPS field was modified with non-occurrence diagnostic data prior to the analysis. In further experiments an initial-guess field was generated by an averaging procedure from RAOBS and occurrence-diagnostic data.

(d) Relative Weighting Matrix The relative weighting matrix determines the weight given to the correction made by an individual humidity diagnosis in the SAT analysis [see Eq. (VI-3)] relative to the weight given to the RAOB (always 1). When a humidity diagnosis is used in the analysis, the data weight correction is bounded by zero and one. With a weight of one, the humidity diagnosis correction is weighted equivilent to a RAOB. Within the indicated range, the numerical weight of the correction is provided to the analysis from a table typified by Table XXV. The table is a 5 times 5 matrix, in which each of the 25 possible values is defined uniquely by the reliability RI of the diagnosed or observed data and the density of stations ρ about the surface station or radiosonde station that is providing the humidity data. The values of the RI and ρ categories are also provided to the analysis program and these values are the lower limit of the category. Table XXVI gives the category values used and their significance.

TABLE XXV

RELATIVE WEIGHTING MATRIX (RWM)

Density category (ρ)	Reliability category (RI)			
	RI_1	RI_2	. . .	RI_5
ρ_1	RWM_{11}	RWM_{12}	. . .	RWM_{15}
ρ_2	RWM_{21}	RWM_{22}	. . .	RWM_{25}
.	.	.		.
.	.	.		.
.	.	.		.
ρ_5	RWM_{51}	RWM_{52}	. . .	RWM_{55}

TABLE XXVI

CATEGORY LIMITS OF RELATIVE WEIGHTING MATRIX

(a)

Reliability indicator (RI)

Value	Explanation
.5	REEP diagnosis - RI_1 $.5 \le Pr^* < .6$
.6	REEP diagnosis - RI_2 $.6 \le Pr^* < .7$
.7	REEP diagnosis - RI_3 $.7 \le Pr^*$
1.0	Indicator for decision-tree diagnosis - RI_4
2.0	Indicator for RAOB-RI_5

*Pr = probability of occurrence

(b)

Station densities (ρ)

Value	Explanation
0	Number of stations in area $0 \le \rho_1 < 2$
2	Number of stations in area $2 \le \rho_2 < 4$
4	Number of stations in area $4 \le \rho_3 < 7$
7	Number of stations in area $7 \le \rho_4 < 10$
10	Number of stations in area $10 \le \rho_5$

As indicated in Table XXVI, there are 5 categories each of reliability and of density. All pieces of information used in the analysis will fall into one category of RI and ρ and thus the value of RWM is determined. RI is divided into 3 categories of increasing probability of occurrence for the REEP diagnoses and one category each for decision-tree diagnoses and RAOBS. The method of computing densities is described in Subsection 11, but in general, the numerical value indicates approximately the number of RAOBS and humidity diagnoses in a square of 2 x 2 NWP grid intervals (about 400 miles in the test area). Thus, less than 2 observations and diagnoses indicates very limited humidity data in the local area, while 10 or more observations and diagnoses indicates that a large amount of humidity data is available in the limited region. Various approaches may be tested for weighting the diagnostic corrections as a function of diagnosis reliability and amount of other data available. A similar procedure has been used in the analysis of 10-mb heights and temperature [12], the main difference being that the weighting used was a function of data timeliness (past data were used) and of data density.

(c) Analysis Characteristics The analysis options which will strongly influence the final humidity analysis are: the number of SAT corrections used; the size of the influence radius (R) which defines the area about each grid point within which data are used to correct the grid point DPS; and the degree of smoothing (if any) used between each correction.

It has been demonstrated [13] that the size of the influence radii will strongly influence the scale of the parameter features that predominate in the analysis. Smoothing can be used in the following form [13]:

$$S(i,j) = \frac{DPS(i,j) + b\,\overline{DPS}}{1 + b} \qquad \text{(VII-1)}$$

where S(i, j) is the resultant smoothed DPS at the grid point, DPS(i, j) is the unsmoothed value at the grid point, $\overline{DPS}$ is the mean value of dew-point spread at the 4 surrounding grid points and b is a constant that determines the degree of smoothing (the value of b is a variable input to the analysis). If b = 0 no smoothing is used; if b = 1 the mean value of DPS at the 4 surrounding grid points is weighted equal to the unsmoothed value of DPS at the central grid point. When relatively strong smoothing (such as b=1) is used, small scale irregularities (as well as real features) tend to be surpressed [13].

Most of the experiments described in the next section are concerned directly with the incorporation of the diagnostic data into the analysis in a variety of ways. In these experiments it was necessary to compare identical SAT analysis procedures to evaluate the impact of the diagnostic data on the analysis. However, a limited number of experiments were conducted in which differing SAT correction procedures and (in particular) smoothing were used.

18. Results

In each of the experiments performed, a comparison was made of the analyzed values of DPS at grid points with the verification grid field, in the form of a 5 x 5 contingency table with categories of 3°C for 850 mb, 4°C for 700 mb and 5°C for 500 mb. The resultant category limits shown in Table XXVII were arbitrarily chosen, and reflect the differing moisture conditions at the three levels. Table XXVIII is an example of a contingency table showing the results of an experiment with 850-mb data in which: only RAOBS are used; the initial guess is derived from the CPS data; the data density is high; and smoothing (b=0. 1) is performed. The table is a composite of the individual contingency tables resulting after the final SAT correction for each of the 22 observation times. The percent correct (in this case 53.9%) is the statistic shown in the following tables in this section. The corresponding rms errors shown in these tables are the overall rms errors at all grid points within the verification area for all 22 observation times.

TABLE XXVII

CONTINGENCY TABLE LIMITS FOR 850-, 700-, AND 500-mb DPS

Level	Category Limits (°C)				
	1	2	3	4	5
850	0 - <3	3 - <6	6 - <9	9 - <12	≥12
700	0 - <4	4 - <8	8 - <12	12 - <16	≥16
500	0 - <5	5 - <10	10 - <15	15 - <20	≥20

TABLE XXVIII
CONTINGENCY TABLE EXAMPLE

		Verification Analysis					
		1	2	3	4	5	Total
Analyzed	1	455	119	24	12	10	620
	2	182	205	60	21	10	478
	3	28	78	67	20	10	203
	4	12	20	25	25	8	90
	5	2	3	6	16	27	54
Total		679	425	182	94	65	1445
Hits = 779					Percent correct = 53.9		
Hits ±1 category = 1287					Percent correct = 89.1		

Experiments were performed, for each of the 3 types of data densities, in which only radiosonde observations were used. In all these experiments the initial guess consisted of the IGDPS field (12-hr trajectory forecasts of CPS converted to DPS); three SAT corrections having influence radii of 2.0, 1.5, and 1.0 were performed, and smoothing, ranging from very light (b=0.1) to moderately heavy (b=1.0), was used.

The overall rms errors and percent-correct statistics given in Table XXIX for these experiments illustrate (a) the quality of the DPS initial guess, (b) the improvement of the initial-guess field that results from the SAT corrections using RAOB data of different density and (c) the effects of using smoothing of different intensities.

In the examination of the effects of smoothing on the rms error statistics shown here and in the following tables we must be aware of certain factors. Smoothing, by its very nature, tends to lower maximum points, raise minimum points and reduce gradients. This may or may not improve the analysis, but the point to be made is that the likelihood of encountering large errors in the analysis is decreased, which therefore increases the chances of obtaining a lower rms error. It is probable that a better analysis is achieved only if a corresponding increase is also noted in the overall percent-correct score obtained from the contingency table.

TABLE XXIX
ANALYSIS VERIFICATION STATISTICS USING RAOB DATA ONLY

Level (mb)	Density	Smoothing (b)	Overall rms error	Overall % correct
850	IGDPS unmodified		4.26	39.0
	Low	0.1	4.02	41.9
		1.0	3.61	41.0
	Medium	0.1	3.67	46.4
		0.5	3.37	47.2
	High	0.1	3.17	53.9
		0.5	2.95	55.0
700	IGDPS unmodified		5.34	35.9
	Low	0.1	5.00	38.7
		0.5	4.71	37.9
		1.0	4.65	38.3
	Medium	0.1	4.58	44.7
	High	0.1	3.96	50.6
		0.5	3.71	51.5
		1.0	3.71	48.6
500	IGDPS unmodified		5.28	43.7
	Low	0.1	4.91	44.8
		0.5	4.52	45.1
		1.0	4.41	45.8
	Medium	0.1	4.34	50.6
		0.5	3.94	52.6
		1.0	3.83	52.4
	High	0.1	3.85	58.4
		0.5	3.48	59.1

The statistics in Table XXIX illustrate the following two points:

(a) The quality of the final analysis is highly dependent on the quality of the initial-guess field. Only when a dense network of RAOBS (found in very few regions of the Northern Hemisphere) were used, did the improvement from the initial guess result in a large reduction of the rms error and a large increase in pereent-correct score.

For example, at 500 mb, with a dense network of RAOBS and using moderate smoothing, the rms error was reduced from 5.28 to 3.48 and the percent correct increased from 43.7 to 59.1.

(b) More severe smoothing, while nearly always lowering the rms error, will frequently result in a lower contingency table percent-eorreet score. This is particularly true of higher data densities, and is most vividly illustrated at the 700-mb level where, with a high density of RAOBS, an increase in degree of smoothing from b=0.5 to b=1.0 resulted in the rms error remaining unchanged, but the percent-correct score decreasing from 51.5 to 48.6.

The primary purpose of the humidity analysis developmental testing was to determine the effects of introducing diagnostic data into the analysis. The results shown in Table XXIX merely give an indication of the improvements that are obtained as more dense RAOB data are used to correet the initial guess, as well as the effects of using various degrees of smoothing after each SAT eorreetion. The remainder of this section will be devoted to the utilization of the diagnostic data in the analysis. For eomparative purposes, referenee will be made to Table XXIX.

The various relative weighting matrices that were used to modify the SAT eorrections made by RAOB and diagnostic data are given in Table XXX. In all but two relative weighting types, all radiosonde data are weighted one. In two types (I and K), RAOBS are excluded from the analysis to observe the effeets that result when only diagnostie data are used. Only decision-tree diagnostie data (in addition to the RAOB data) are used in relative weighting types B and C. Only REEP diagnostic data are used in type E. In type J, REEP data having a eategory probability

TABLE XXX
RELATIVE WEIGHTING MATRIX TYPES

Type A

0	0	0	0	1
0	0	0	0	1
0	0	0	0	1
0	0	0	0	1
0	0	0	0	1

Type B

0	0	0	1	1
0	0	0	1	1
0	0	0	1	1
0	0	0	1	1
0	0	0	1	1

Type C

0	0	0	.5	1
0	0	0	.5	1
0	0	0	.5	1
0	0	0	.5	1
0	0	0	.5	1

Type D

.4	.5	.6	.6	1
.3	.4	.5	.5	1
0	.3	.4	.4	1
0	0	.3	.3	1
0	0	.3	.3	1

Type E

.5	.5	.5	0	1
.5	.5	.5	0	1
.5	.5	.5	0	1
.5	.5	.5	0	1
.5	.5	.5	0	1

Type F

.5	.5	.6	.6	1
.4	.4	.5	.5	1
.3	.3	.4	.4	1
.3	.3	.3	.3	1
.3	.3	.3	.3	1

Type G

.5	.6	.7	.6	1
.5	.6	.7	.5	1
.5	.6	.7	.3	1
.5	.6	.7	.3	1
.5	.6	.7	.3	1

Type H

.8	.8	.8	.6	1
.8	.8	.8	.5	1
.7	.7	.8	.3	1
.6	.6	.7	.2	1
.6	.6	.7	.2	1

Type I

.5	.6	.7	.6	0
.5	.6	.7	.5	0
.5	.6	.7	.3	0
.5	.6	.7	.3	0
.5	.6	.7	.3	0

Type J

0	.8	.8	.6	1
0	.8	.8	.5	1
0	.7	.8	.3	1
0	.6	.7	.2	1
0	.6	.7	.2	1

Type K

.4	.5	.6	.6	0
.3	.4	.5	.5	0
0	.3	.4	.4	0
0	0	.3	.3	0
0	0	.3	.3	0

of a less than 0.60 are excluded. The remaining relative weighting types use RAOBS, decision-tree diagnoses, and REEP diagnoses with variations occuring in the relative weight given to corrections made by the diagnostic data.

The overall final-pass (after three SAT corrections) rms error and percent correct contingency table scores at 850, 700 and 500 mb are given for the various relative weighting types in Table XXXI. The data density simulated and the degree of smoothing applied is indicated for each experiment. In each analysis three SAT corrections were made, with influence radii of 2.0, and 1.5 and 1.0.

Only a limited number of analyses of 850-mb DPS were made. Humidity diagnosis and analysis testing is perhaps least interesting at this level because of the predominance of observed moist conditions and the fact that the diagnostic data is almost entirely limited to decision-tree diagnoses (moist).

TABLE XXXI
ANALYSIS VERIFICATION STATISTICS USING RAOB AND DIAGNOSTIC DATA

Level (mb)	Density	Relative weighting type	Smoothing (b)	Overall final pass rms error (°C)	Overall final pass % correct
850	Low	B	0.1	3.72	47.0
		B	1.0	3.51	46.3
		C	0.1	3.72	45.2
		D	0.1	3.68	43.8
		G	0.1	3.68	43.7
850	Medium	B	0.1	3.55	48.9
		B	0.5	3.40	48.4
		C	0.1	3.53	47.0
		D	0.1	3.51	46.1
		G	0.1	3.49	46.3

TABLE XXXI (Continued)

Level (mb)	Density	Relative weighting type	Smoothing (b)	Overall final pass rms error (°C)	Overall final pass % correct
700	Low	B	0.1	5.18	39.2
		C	0.1	4.96	39.4
		D	0.1	4.90	40.2
		E	0.1	4.95	39.6
		G	0.1	4.89	40.1
		G	0.5	4.66	40.1
		G	1.0	4.62	40.0
		H	0.1	4.92	39.7
		I	0.1	5.12	38.5
		I	1.0	4.84	38.2
		J	0.1	5.00	40.1
700	Medium	C	0.1	4.63	42.5
		E	0.1	4.44	44.9
		D	0.1	4.53	43.1
		G	0.1	4.51	43.3
500	Low	B	0.1	5.19	42.6
		C	0.1	4.78	46.3
		D	0.1	4.77	47.0
		D	0.5	4.40	48.2
		D	1.0	4.30	48.2
		E	0.1	5.03	44.3
		F	0.1	4.79	46.3
		G	0.1	4.82	46.1
		H	0.1	4.89	44.9
		H	0.5	4.51	46.1
		K	0.1	4.99	45.1
		K	1.0	4.23	46.7
500	Medium	B	0.1	4.79	46.9
		C	0.1	4.41	49.9
		D	0.1	4.37	51.0
		E	0.1	4.47	49.2
		F	0.1	4.39	50.8
		F	0.5	4.01	50.7
		F	1.0	3.95	50.2
		G	0.1	4.42	50.5
		I	0.1	4.93	45.4

It would be expected that, with sparse or intermediate (low or medium) density conditions, an analysis with RAOBS only would be more likely to produce larger positive errors than negative errors (that is, analyzed DPS would be too high) simply because the "correct" (verification) analysis is generally moist (low DPS). The addition of diagnostic data largely eliminates these positive errors and therefore yields improved verification statistics. It is seen from comparing Tables XXIX and XXXI that the improvement is greatest in the sparse-data simulation with all decision-tree diagnostic data being weighted equal to RAOBS and no REEP diagnostic data included (type B). Under these conditions, and with light smoothing used (b=0.1), the introduction of the diagnostic data into the analysis results in an improvement in final-pass rms errors from 4.02° C (RAOB only) to 3.72°C, and percent correct of 41.9 (RAOB only) to 47.0. If strong smoothing is used with the same relative weighting type, the final-pass rms error is again reduced but the percent-correct score also decreases slightly. If the decision-tree diagnoses are weighted one half of RAOBS (type C), or if REEP diagnostic data is introduced into the analysis and the relative weight given decision-tree diagnoses reduced (type D and G), the percent-correct scores are still lower. The above comments apply, in general, to the medium-data simulation also, except that the improvements obtained using decision-tree diagnostic data are more modest. The final pass rms error improves from 3.67° C to 3.55° C, and the percent correct from 46.4 to 48.9, when the relative weighting type is B and a light smoothing (b=0.1) is applied.

At the 700-mb level a large variety of relative weighting types were used, particularly for the simulation of sparse-data conditions. Unlike the results obtained at 850 mb, the use of type B at 700 mb did not produce the best verification statistics. In fact, again referring to both Tables XXIX and XXXI, it is seen that with a sparse-data simulation and light smoothing (b=0.1), the rms error increases from 5.00°C to 5.18°C. It seems clear that the use of decision-tree diagnostic data only, weighted equivalent to a RAOB, produces an analysis that is too moist. If the decision-tree diagnostic data is weighted one-half that of RAOB (type C) the rms error is reduced to 4.96. The best verification statistics are, however, obtained when both decision-tree and REEP data are included in the analysis. Recall, from Tables XXII and XXIII, that 700-mb REEP diagnoses are both moist and dry, and that the ratio of REEP diagnosis to decision-tree diagnosis is much higher at the 700-mb level than at the 850-mb level. About the same score is obtained when the REEP diagnoses are weighted relatively lightly (type D) or moderately (type G). A feature common to both relative weighting types (See Table XXX) is that in areas where the density of RAOB and diagnostic data is relatively high ($\rho > 4$), the decision-tree data is weighted less than half the RAOB data. The reasoning behind this is that within a large area of simulated sparse or intermediate density, small regions of relatively-high data density result primarily from the identical or similar decision-tree diagnoses being made at all or most of the available surface stations within the limited region. While this tends to increase the reliability of the diagnosis, it also results in the introduction of redundant information into the analysis. If a fairly high relative weight (one-half or greater) is given to each individual SAT correction resulting from the decision-tree diagnoses in these high-density regions, an over-correction is quite possible. This apparently occurs when types B or C are used. It is interesting to note again that, with type G used, the percent-correct score remains almost constant as smoothing varies from b=0.1 to b=1.0. The rms error score, on the other hand, decreases from 4.89°C to 4.62°C.

Some additional experiments that were attempted were to use RAOB data with REEP diagnoses only (type E); to give high relative weight to REEP diagnoses (type H); and to exclude REEP diagnostic data having a probability of occurrence less than .60 (type J). These variations did not improve the verification statistics. Finally, diagnostic data given a relative weight identical to type G were introduced into the analysis with <u>all</u> RAOB data <u>excluded</u> (type I). Here, we obtain a measure of the improvement in the analysis, over the IGDPS field, that can be achieved using only diagnostic data, and to a certain extent, we simulate an ocean region where no upper-air data are available, but surface ship reports are. Under these conditions, and using smoothing of b=0.1, the rms error of the initial guess field is decreased from 5.34°C to 5.12°C, and the percent correct score increased from 35.9 to 38.5. When only radiosonde data of sparse density were used (See Table XXIX) with equivalent very light smoothing, the final pass rms error was reduced to 5.00°C and the percent correct increased to 38.7. Thus, in the data-sparse simulation at 700 mb, considering the percent-correct improvement in particular, the diagnostic data alone improve the initial guess about the same extent as does the use of RAOB data only. When strong smoothing (b=1.0) was applied with type I being used, the rms error decreased to 4.84°C, but the percent-correct score also decreased to 38.2.

In the experiments conducted with a simulation of intermediate data density at 700 mb, no measureable improvement in the verification statistics was obtained with the introduction of diagnostic data into the analysis. When relative weighting types E, D, and G were employed with light smoothing, a small reduction in rms error is noted, but the percent-correct score is either lower or remains about the same when compared to that obtained using RAOB data only.

The results obtained at the 500-mb level were, in general, quite similar to those of the 700-mb level. For a data-sparse simulation and using type B, with light smoothing, the rms error increased (from using RAOB data only) from 4.91°C to 5.19°C, and the percent correct decreased from 44.8 to 42.6. An improvement is noted with type C, but the best verification statistics are again obtained with type D, when light smoothing is employed. The rms error is reduced to 4.77°C and the percent correct increased to 47.0. Moderate smoothing (b=0.5) further lowers the rms error to 4.40°C and raises the percent correct to 48.2. Application of heavier smoothing (b=1.0) fails to increase the percent-correct score. Three other types of data weight corrections (relative weighting types F, G and H) were attempted in which the REEP diagnostic data are given greater relative weight. The verification statistics were, for each, inferior to those obtained with type D. This was also true when type E (RAOBS and REEP diagnostic data only) was used. Finally, the identical corrections as in type D were used without RAOB data (type K). With strong smoothing, an rms error of 4.23°C, and a percent-correct score of 46.7, were obtained. With strong smoothing (b=1.0) and using RAOB data only, an rms error of 4.41°C and a percent-correct score of 45.8 were obtained (see Table XXIX). The use of diagnostic data alone considerably improves the IGDPS scores (rms error=5.28°C and percent correct = 43.7) and the improvement is greater than that realized when only RAOB data alone is available to the analysis. The experiments in which an intermediate (medium) data density was simulated at 500 mb led to the conclusion that the addition of diagnostic data to the analysis is not warranted for this data density. A comparison of the pertinent sections of Tables XXIX and XXXI shows that, for a given degree of smoothing, the use of diagnostic data in the analysis failed to improve the verification statistics obtained with RAOBS alone, regardless of the relative weighting type used.

A number of experiments were conducted at 700 mb in which the method of obtaining the initial guess to be used in the analysis varied. All previous analysis results summarized in Tables XXIX and XXXI were obtained using an IGDPS (12-hr trajectory forecast of CPS converted to DPS) initial guess. Two other types of initial-guess fields are possible and the methods of obtaining them were described in detail in Section VI. In one type, the IGDPS field is modified using REEP non-occurrence diagnostic data. In the second type, the initial guess is generated by an averaging procedure from the data to be used in the analysis. The rms error and percent-correct scores given in Table XXXII are those of the "final" initial guess, that is, those grid-point values of DPS upon which the first SAT correction is applied. It is seen immediately that the use of non-occurrence REEP data to modify the IGDPS grid field results in very little change in the rms errors or percent-correct scores. The relatively limited number of this type of diagnostic data available after simulating sparse or medium data densities is apparently responsible for this result (see Tables XXII for the total number of these diagnoses). On the other hand, the use of a generated initial guess with an intermediate data density simulation raises the percent-correct score from 35.5 to 40.6 (for RAOBS only) and to 40.7 (for RAOBS and diagnostic data). The corresponding changes in

TABLE XXXII

ANALYSIS VERIFICATION STATISTICS WITH DIFFERENT INITIAL-GUESS FIELDS

Level (mb)	Density	Initial guess	Overall initial guess rms error (° C)	Overall initial guess % correct
700	—	IGDPS	5.34	35.9
	Low	Modified IGDPS	5.31	35.9
	Medium	Modified IGDPS	5.29	35.5
	Medium	Generated (RAOB only)	5.41	40.6
		Generated (RAOB & diagnostic)	5.18	40.7

rms error are from 5.34°C to 5.41°C and 5.18°C. It would seem from the above percent-correct scores that the use of a generated initial guess, at least in areas of moderate data density, is desirable. This is, however, not actually the case. An initial-guess field that has been generated by an averaging procedure represents essentially a very smoothed "fit" of the analysis data. Subsequent application of the SAT correction procedure will result in only limited modification of the initial guess, particularly when the number of corrections is limited (as is the case in data-sparse simulation or when using RAOBS only in intermediate data simulation). Thus, when two identical analyses were preformed with RAOBS only, the final-pass statistics when the IGDPS initial guess was used (4.58°C and 44.7) were considerably better than those obtained if the initial guess was generated (5.36°C and 41.4). If diagnostic data are included and an identical analysis procedure and relative weighting type used, the differences are very small, but the final-pass results obtained using a generated initial guess were slightly inferior.

A series of experiments were conducted in which analyses were performed only over the western half of the grid (western Europe). The data on this half of the grid contains two important characteristics: (a) the IGDPS data is derived from 12-hr CPS trajectories that originated in many instances over the eastern Atlantic

Ocean, and (b) the distributions of RAOBS and surface stations is quite uneven, because large bodies of water (eastern Atlantic Ocean, North Sea, Norwegian Sea, Baltic Sea, and Bay of Biscay) are located on the western edge of the grid.

Table XXXIII gives the initial-guess and final-pass rms errors and percent-correct scores for the 700-mb level for the sparse data (low density) simulation. It is seen immediately that the IGDPS initial guess is less accurate in this region than in the entire area. The rms error is 6.25°C compared with 5.34°C for the entire area, while the associated percent-correct scores are 29.7 and 35.9 respectively. Type G, one of the two relative-weighting matrices that proved most useful in weighting diagnostic data at 700 mb, for SAT corrections within the entire area, was used in the limited western area. With light smoothing (b=0.1), the rms error of the initial guess is lowered to 5.61°C, and the percent-correct score is 35.7. With heavy smoothing the rms error is 5.15°C, and the percent correct, 36.6. Unlike the results that were obtained when the entire area was considered (see Table XXXI), the application of heavy smoothing with the type G data weight correction, and low density simulation, did improve the verification statistics. This result is probably a reflection of the fact that the initial guess is of lower quality, and the data used in the analysis are distributed more irregularly. It should also be noted from Table XXXIII that, for the same smoothing, the addition of diagnostic data to the analysis improved the rms error and percent-correct scores over those obtained using RAOBS only. The use of a generated initial guess with DWC type G did not improve the final-pass statistics. Considering the irregular data distribution, it is not surprising that obtaining an initial guess by an averaging procedure fails to improve the analysis.

A number of additional experiments were performed, the results of which have not been given in previous tables. The rms error and contingency table percent-correct scores did not indicate any marked improvement in the analysis. The types of experiments were: (a) increasing the size of the influence radius of the first SAT correction to three NWP grid intervals; (b) performing four instead of three SAT corrections; (c) smoothing the initial guess, as well as after each

TABLE XXXIII
ANALYSIS VERIFICATION STATISTICS FOR WESTERN AREA

Level (mb)	Density	Initial guess	Overall initial guess rms error (° C)	Overall initial guess % correct	Relative weighting correction	Smoothing (b)	Overall final pass rms error (° C)	Overall final pass % correct
700	Low	IGDPS	6.25	29.7	A	0.1	5.75	34.1
		IGDPS			A	1.0	5.24	34.9
		IGDPS			G	0.1	5.61	35.7
		IGDPS			G	1.0	5.15	36.6
		generated	6.55	36.1	G	0.1	6.38	35.7

SAT correction; and (d) using a generated initial guess over the entire test area with sparse data simulation.

Up to this point the discussion has been restricted to summary error statistics obtained over all 22 observation times used in the developmental testing. It is, however, often interesting and instructive to examine individual observation times. A set of maps at the 500-mb level are shown in Fig. 22 (a)-(d) and in Fig. 23 (a)-(d). For each figure the maps are (a) verification or "true" analyses; (b) IGDPS (initial guess); (c) final-pass analysis using RAOB data only for a sparse-data density simulation and light smoothing (b=0.1); and (d) same as (c) except that diagnostic data is added to the analysis with type D weighting. In shaded areas the DPS is above 12°C. M indicates areas of low DPS. Isopleths of DPS are drawn for every 4°C. The isopleths were drawn subjectively (all by the same analyst), but are based on the values of DPS obtained at grid points from the objective SAT analysis. The observation times are 00Z Feb. 11, and one day later, 00Z Feb. 12, 1962. The dates were selected to show instances when the addition of diagnostic data results in an improved analysis.

The main features of the DPS verification analysis (Fig. 22(a)) for 00Z Feb. 11, 1962 are:

(a) a small area of large DPS (maximum 23°C) in the southwest corner of the grid,

(b) an area of moderately high DPS extending north-south just west of the center of the analysis area, with two distinct centers of DPS maximum of 15°C,

(c) a broad area of high DPS over much of the eastern third of the grid, with maximum values again of 15°C, and

(d) only limited regions where the DPS is moist (4°C or less); the two most noticeable of which extend north-south in the western portion of the area and occupy a small area on the northern edge of the grid just east of center.

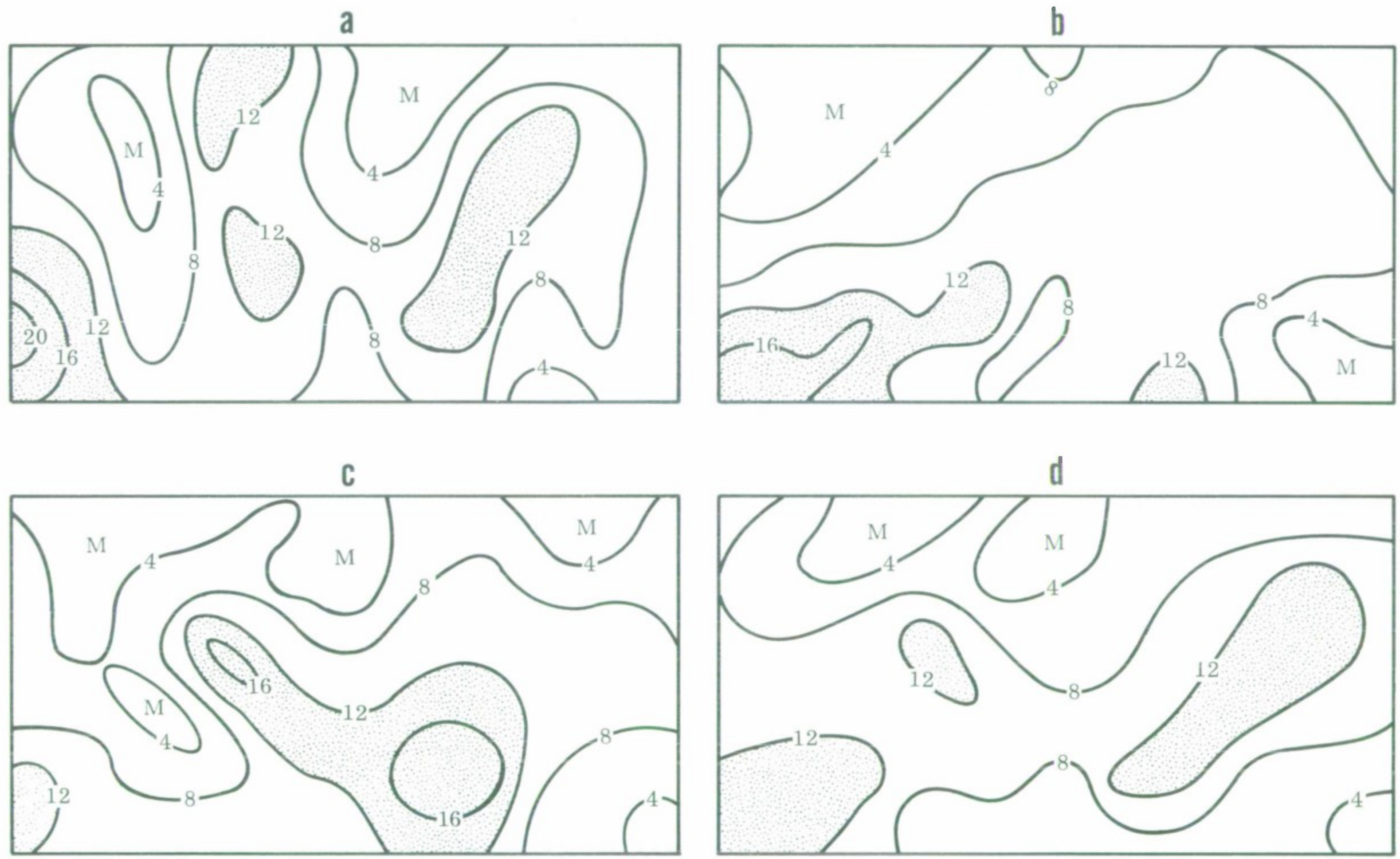

Fig. 22. 500-mb DPS analyses for 00Z February 11, 1962: (a) 500-mb verification analyses, (b) 500-mb IGDPS, (c) 500-mb RAOB only, (d) 500-mb RAOB and diagnostic data.

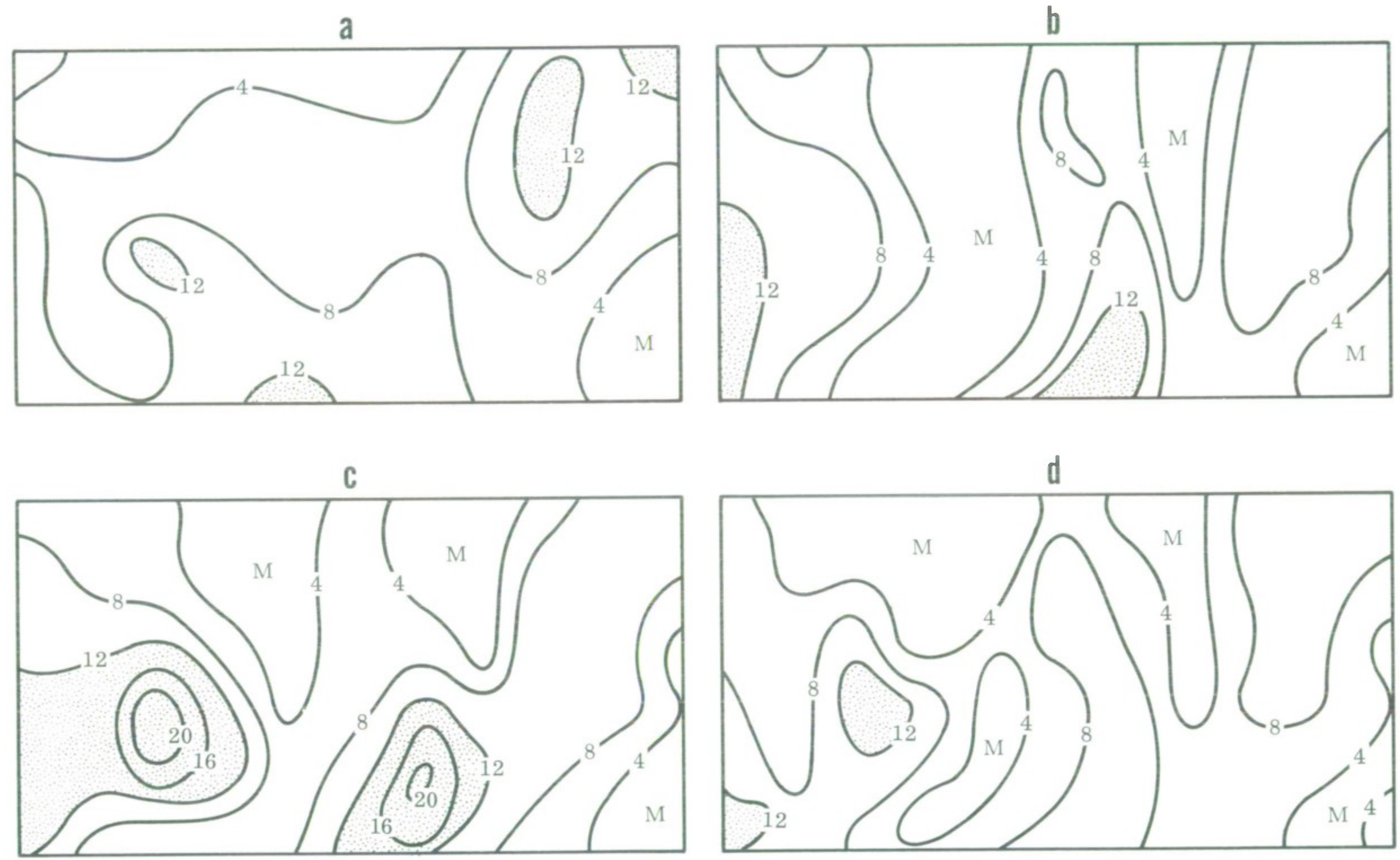

Fig. 23. 500-mb DPS analyses for 00Z February 12, 1962. (a) 500-mb verification analyses, (b) 500-mb IGDPS, (c) 500-mb RAOB only, (d) 500-mb RAOB and diagnostic data.

The IGDPS initial guess [Fig. 22(b)] shows only fair correspondence with the verification analysis. The major region of high DPS extends mainly east-west from the south-west corner toward the south-central part of the analysis area. Two of the maxima described in (a) and (b) have essentially been combined. The broad area of high DPS in the eastern regions compares well with the verification analysis, except that the grid-point values average about 4°C too low. The IGDPS is most deficient in that the northern-most of the two maxima described in (b) is replaced by an area of low DPS, and in place of the southern half of the north-south DPS trough listed in (d) there is a region of maximum DPS.

The sparse-data RAOB-only analysis given in Fig. 22(c) has some serious deficiencies. Generally speaking, the northern half of the analysis is too moist. The center of the region of high DPS in the east (c) is analyzed too far south and the value of DPS is too high. The northern-most of the two maxima described in (c) does not appear in the analysis at all. The area of maximum DPS in the south-west is too small and the values too low.

A glance at Fig. 22(d), the DPS analysis obtained when both radiosonde and diagnostic data are used, shows that the location and size of regions of large DPS more nearly correspond to the verification analysis. The exception is the northern-most of the two maxima, described in (b). The one feature of the RAOB-only analysis that is superior (although faulty) to the analysis with diagnostic data is the depiction of the north-south DPS trough in the western portion of the grid. In general, it can be said that most of the improvement to the analysis resulted from the addition of decision-tree and REEP diagnoses of dry conditions to a radiosonde-only analysis that was too moist.

A detailed discussion will not be given of the same sets of 500-mb DPS grid fields shown one day later in Fig. 23(a)-(d). A comparison of the two verifications analyses shows that marked changes occurred in the humidity distribution in 24 hours. Generally, more moist conditions prevail. The principal faults in the RAOB-only analysis is that the values at centers of maximum and minimum DPS are too extreme. This deficiency is largely corrected by the introduction of diagnostic data into the analysis. Unlike the previous maps shown, the greatest improvement results from the inclusion of moist diagnoses which reduce the erroneously high DPS maxima.

Because of the extent and detail of the material presented in this section it would seem worthwhile to conclude with a summary discussion in the next few paragraphs. First, a few words of caution. The testing was conducted in a limited area of the Northern Hemisphere (Europe) for 22 consecutive observation times (11 days) in Feb. 1962. Much of this region is under a winter maritime regime and the characteristics of the DPS analyses at 850, 700 and 500 mb would be expected to reflect any climateological bias associated with such a regime. The extent and persistence of high humidity at 850 mb, and the relatively high percentage of surface stations that yielded diagnoses with particular cloud and weather types, reflects this bias. The data-density simulations represent, at best, an attempt to approximate characteristic data densities that are found in the Northern Hemisphere. It is felt that in over half of the area of the Northern Hemisphere data density is similar to that approximated in the sparse-data simulation. One final note of caution is that all analyses were performed on an NWP grid (381 km at 60°N). Several of the conclusions regarding analysis characteristics (influence radii, number of SAT corrections, degree of smoothing) in particular, would have to be modified if a smaller grid interval was used.

However, considering the present overall density of RAOBS in the Northern Hemisphere, it would be difficult to justify the use of a smaller grid interval.

The quality of the final DPS analysis is highly dependent on the quality of the initial-guess field. This is, of course, particularly true in regions of sparse data where the effects of the SAT corrections on the initial grid-point values of DPS are limited. Three types of initial-guess fields were used. The initial guess obtained from 12-hr trajectory forecasts of CPS was less reliable at 700 and 500 mb than at 850 mb and less reliable in the western area than the eastern area of the grid at all levels. The increase in rms error at higher levels is at least partly due to the greater variability of humidity at these levels. The increase in error in the western half of the grid is associated with the fact that the trajectories producing the initial guess here originate from the eastern Atlantic Ocean, a region of sparse data. The modification of this initial guess using REEP non-occurrence diagnostic data was ineffective because of the limited number of these diagnoses (with sparse or medium data density simulations) and also, perhaps, to the very conservative manner in which the IGDPS data was adjusted with them. The use of a generated initial guess (initial guess obtained by an averaging of the data to be used in analysis) did not improve the final analysis under sparse or medium data densities.

The limited testing of the analysis characteristics of the SAT correction procedure indicated that three corrections are sufficient. In fact, the improvement in the analysis (as reflected in lower rms errors or higher percent correct scores from the 5 by 5 contingency tables) is often very small between the second and third correction. The associated influence radii of 2.0, 1.5, and 1.0 yield reasonable results. Moderate smoothing (b=0.5) is useful in regions of sparse data and possibly also in areas of medium data density. Otherwise, very light smoothing (b=0.1) should be applied.

The introduction of diagnostic data into the analyses resulted in improved verification scores at all levels with a sparse data density simulation. For intermediate data density, the effect on the verification statistics was negligible at 700 and 500 mb, while some improvement was noted at the 850-mb level. This small deviation in results at 850 mb is probably linked to the sample characteristics. In general, the improvements in rms error and percent-correct score are relatively small, but probably significant when compared to the improvements that result when RAOBS of intermediate or high density are used in the analysis with the identical initial guess. The testing of different relative weightings given to the diagnostic data indicated that the density of all data in a local region, as well as the type and reliability of the diagnostic data, should be accounted for.

At 700 and 500 mb, the best results were obtained when relative weighting type D was used to weight the diagnostic data. The important features of this data-weight correction are: (a) RAOB data is given full weight; (b) decision-tree diagnoses are weighted less than half (.3 or .4) in local regions where the data density is high (primarily caused by repetitive decision-tree diagnoses — redundant information), and half or greater (.5 or .6) in local regions of sparse data; and (c) REEP diagnoses with a probability of occurrence $P_r \geq .70$ are weighted the same as decision-tree diagnoses, while REEP diagnoses with a lower P_r are weighted less. At 850 mb, REEP diagnoses are unimportant because of their infrequency in the test area and time period. The best verification scores were obtained by weighting the decision-tree diagnoses the same as RAOBS. In experiments at 700 and 500 mb, with data sparse conditions being simulated, it was found that the use of only diagnostic data improved the verification statistics of the initial guess as much or more than did the use of RAOBS only. In areas where no RAOBS are available, application of strong smoothing (b=1.0) may be desirable.

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

A technique to diagnose dew-point spread (DPS) at 850, 700, 500 and 400 mb, using Northern Hemisphere surface-synoptic data, has been developed for both the warm and cold [2] seasons of the year. The approach consists of first isolating, within a step-wise decision-tree framework, those individual surface-observed elements that yield highly reliable estimates of upper-level humidity. After all individual, high-quality diagnostic relations of this type have been exhausted, a statistical technique (REEP) is applied to the remaining cases (residual sample) to derive equations that yield probabilities of occurrence for three categories of moisture. A set of decision-tree relations and REEP equations was derived for each of the four constant-pressure surfaces (850, 700, 500 and 400 mb) for the winter season [2] and for all but the 400-mb level for the summer season.

The decision-tree relations effectively utilize those individual surface element types whose occurrence yields a highly reliable estimate of upper-level DPS. The REEP technique selects surface element types whose occurrence or non-occurrence, in conjunction with the occurrence or non-occurrence of other surface variables, yields information regarding the probabilities of occurrence (by categories) of upper-level DPS.

At 850 and 700 mb all decision-tree diagnoses are moist, while at 500 and 400 mb, both moist and dry diagnoses are made. Diagnoses of both moist and dry categories of DPS are made with REEP. The reliability of a diagnosis is indicated by the probability of occurrence assigned to the diagnosed category.

It is concluded that the combined decision-tree and REEP approach is a logical and fruitful method of diagnosing upper-level moisture from surface observations. Limited comparisons of the warm and cold season decision-trees using independent data indicated that the use of two sets of relationships is useful. The percentage of surface stations that will yield useful upper-level humidity diagnoses varies with season, level, and minimum probability required for a REEP diagnosis to be made.

However, this number is generally between 25 and 50 percent. Since there are more than five times as many stations reporting surface-synoptic data as there are reporting radiosonde observations, the diagnostic technique described in this report provides a vast increase in humidity information.

The humidity diagnoses, while useful, are of variable quality. It is still necessary to know how to combine diagnoses and radiosonde observations of humidity into an analysis and how to determine the effects of the introduction of the diagnostic data.

The incorporation of diagnostic data obtained from the cold season relationships into a SAT (successive approximation technique) humidity analysis on an NWP grid at the 850-, 700-and 500-mb levels is tested using European surface and upper-air data for 22 consecutive observation times in February 1962. Various data densities are simulated by withholding a portion of both surface and upper-air data. Root-mean-square errors and contingency table statistics indicate that an improved analysis is obtained in sparse-data regions by weighting the analysis corrections made by the diagnostic data relative to the radiosonde data corrections. The most appropriate weighting is a function of the reliability of the diagnosis and the data density in the area local to the diagnosis. At 850 mb, the addition of decision-tree data only (no REEP diagnoses) most improved the analysis. At 700 and 500 mb, the combined use of both decision-tree and REEP diagnoses was useful. The diagnostic data receives increasing relative weight as its reliability increases and the density of data (both observed and diagnosed) in the limited area about the diagnosis decreases. In general, the improvements in rms error and percent-correct score are relatively small, but probably comparable to the improvement that would result if the number of RAOBS was increased from six to nine or ten in an area of the size used in the developmental tests. Considering the cost of maintaining weather ships in data-sparse ocean regions, an improvement of this magnitude is significant.

The humidity analysis technique was tested within a limited area and time period. The results, however, do indicate that in sparse data regions of the Northern Hemisphere (over half the total area) it is desirable to include diagnostic data with whatever RAOBS are available in obtaining a humidity analysis. Certain features of the SAT technique, such as the number of corrections, size of influence radii, and degree of smoothing used, will effect the analysis. The testing indicated that the most important of these is smoothing, and that in data-sparse regions moderate or heavy smoothing should be applied after each SAT correction.

It is recommended that the following additional development and testing be performed.

A more complete comparison should be conducted between the warm-season decision trees and REEP equations and the cold-season decision trees and REEP equations. It has been suggested that, considering the developmental samples, the warm-season relations should be used from July through November and the cold-season relations from November or December through June. Testing for selected months of the year, using surface and upper-air data from several regions of the Northern Hemisphere, would provide firmer guidelines regarding the use of one or the other set of relations.

An expanded testing of the analysis technique is also advisable, using data from a different area and time of the year than was used here. This study should include a careful examination of the changes in error fields of individual analyses that result when diagnostic data is used. Particular attention should be directed toward the distribution of data as well as the overall density.

It has been seen that the quality of the resultant analysis is highly dependent on the quality of the initial guess in data-sparse regions. Further effort should be directed toward improving the initial guess by either (a) more extensive modification of the initial guess using diagnostic data, or (b) modification or expansion of the present GWC trajectory prediction technique. The first suggestion has only limited promise because the frequency of diagnostic data is limited in data-sparse regions and the extensive utilization of these data to both modify the initial guess and contribute to SAT corrections tends to be redundant. In the second approach, an evaluation should be conducted of the predictive skill of the present trajectory technique first, and then an estimate should be made of the likelihood of improvement through additional physical or dynamical modeling.

Continued effort should be directed toward the design of an upper-air observation network and associated transmission procedures that would result in significant improvement in both the horizontal and vertical depiction of moisture.

APPENDIX

REDERIVATION OF 850-mb COLD-SEASON REEP RELATIONSHIPS

The cold-season REEP equations used to diagnose 850-mb DPS, if a decision-tree diagnosis cannot be made, were rederived: the results presented here are to replace the equations given in the earlier report [2].

1. Variables Selected

In the statistical evaluation of the 850-mb residual sample, 3 and 4 categories of 850-mb DPS were used (see Table XXXIV).

TABLE XXXIV
850-mb COLD SEASON DPS CATEGORY LIMITS

Category	Limits (° C)	Category	Limits (° C)
1	$0 \leq DPS \leq 4$	1	$0 \leq DPS \leq 5$
2	$4 < DPS \leq 8$	2	$5 < DPS \leq 10$
3	$8 < DPS \leq 13$	3	$10 < DPS$
4	$13 < DPS$		

The dummy variables selected by REEP to diagnose 3 and 4 categories of 850-mb DPS (specificand) are quite similar (see Table XXXV). For both specificand breakdowns, the first two dummy variables selected are dry and moist categories of surface DPS. This, of course, simply reflects the strong positive correlation found between moisture at the surface and 850 mb. The third dummy variable selected, low-cloud height greater than 8,000 feet or no low cloud, contributes significantly to a non-occurrence of category 1 (moist) and an occurrence of category 3 (dry) in the 3-category specificand breakdown. This, of course, is consistent with meteorological reasoning.

2. Evaluation of Results on Dependent and Independent Data (850-mb)

The REEP equations developed to diagnose 4 and 3 categories of 850-mb DPS were tested on a dependent sample of 5328 cases and an independent sample of 1276

TABLE XXXV
850-mb RESIDUAL SAMPLE-SELECTED VARIABLES

Order of selection	Variables Selected	
	4-category diagnosis	3-category diagnosis
1	$10 < DPS$	$10 < DPS$
2	$0 \le DPS \le 3$	$0 \le DPS \le 3$
3	$8000 \le h$ (or no low cloud)	$8000 \le h$ (or no low cloud)
4	$-5 < T_d \le 10$	$T \le -15$
5	$6 < DPS \le 10$	$-15 < T \le 0$
6	$-15 < T \le 0$	$N_T = 0.0$
7	$N_T = 0.0$	$6 < DPS \le 10$
8	$T \le -15$	ww = 02
9	ww = 02	$-3.1 < app \le -1.6$
10	$10 < DPS \le 17$	$-5 < T_d \le 10$
11	$0.1 < N_T \le 0.5$	$C_L = 5$
12	$-3.1 < app \le -1.6$	-
13	$15 < T \le 30$	-
14	$0 < T \le 15$	-
15	$1.5 < app \le 3.0$	-

cases. The contingency table results are presented in Table XXXVI. In both 4 and 3 category diagnoses, the percent-correct score varies little from dependent to independent data. The frequency of diagnoses in each category compares very well with the observed frequency in the 3 category contingency table and not as well in the 4 category table. Considering the independent sample results, the percent-correct scores are 41.9 and 52.0 for 4 and 3 category diagnoses respectively. These scores are only slightly lower (about 1 percent) than those obtained with the 700-mb cold-season residual-sample REEP equations [2].

A comparison of the approaches of the decision tree plus REEP with REEP only was made with the rederived relationships and the only effect of introducing the results described here was to emphasize further the superiority of the decision tree plus REEP approach. The comparison of the use of Boolean and non-Boolean variables with the 850-mb residual sample was redone with the new relationships. The results obtained were the same as before; that is, the use of Boolean variables does not increase the diagnostic skill (for a detailed discussion of these comparisons the reader is referred to the earlier report [2]).

3. Recommended Procedure at 850 mb and Additional Comments

Table XXXVII contains the two sets of coefficients for the REEP equations used to diagnose 4 and 3 categories of 850-mb DPS. It is recommended that the 3 category REEP equations for 850 mb be used if a diagnosis cannot be made from the the 850-mb cold-season decision tree.

TABLE XXXVI

850-mb RESIDUAL SAMPLE (COLD SEASON)

(a) Dependent-data specification of dew-point spread

(i) 4 categories

		Observed				Total
		1	2	3	4	Specified
Specified	1	278	205	108	131	722
	2	562	967	528	465	2522
	3	44	183	298	170	695
	4	128	258	375	628	1389
Total Observed		1012	1613	1309	1394	5328
Number of Hits		2171		Percent Correct 40.8		

(ii) 3 categories

		Observed			Total
		1	2	3	Specified
Specified	1	764	412	377	1553
	2	376	822	538	1736
	3	320	573	1146	2039
Total Observed		1460	1807	2061	5328
Number of Hits		2732		Percent Correct 51.3	

(b) Independent-data specification of dew-point spread

(i) 4 categories

		Observed				Total
		1	2	3	4	Specified
Specified	1	66	39	32	33	170
	2	141	235	129	103	608
	3	8	46	71	40	165
	4	32	53	86	162	333
Total Observed		247	373	318	338	1276
Number of Hits		534			Percent Correct 41.9	

(ii) 3 categories

		Observed			Total
		1	2	3	Specified
Specified	1	175	101	93	369
	2	102	208	136	446
	3	75	105	281	461
Total Observed		352	414	510	1276
Number of Hits		664		Percent Correct 52.0	

TABLE XXXVII
COEFFICIENTS OF REEP EQUATIONS (850 mb)*

Order	4 Category				3 Category		
	1	2	3	4	1	2	3
1	-.120	-.293	-.090	.503	-.148	-.249	.397
2	.127	-.076	-.041	-.010	.132	-.109	-.022
3	-.172	.003	.060	.109	-.142	.015	.127
4	-.018	-.022	-.011	.051	.130	.007	-.137
5	-.055	-.124	.137	.042	-.052	.110	-.058
6	-.129	-.079	.031	.176	-.072	.030	.042
7	-.092	-.004	.054	.041	-.095	-.017	.113
8	-.022	-.026	-.092	.140	-.057	-.011	.068
9	-.035	-.033	.008	.060	-.069	-.059	.128
10	.039	.016	.183	-.238	-.045	-.021	.067
11	-.062	.008	.023	.032	.098	-.055	-.042
12	-.068	-.050	.005	.113	—	—	—
13	-.083	-.091	-.098	.271	—	—	—
14	-.104	-.143	-.013	.261	—	—	—
15	.014	.042	.005	-.060	—	—	—
Additive constant	.473	.497	.174	-.144	.433	.370	.197

*See Table XXXV for variables selected

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13. ABSTRACT

In the Northern Hemisphere there are more than five times as many stations reporting surface-synoptic data as there are reporting radiosonde observations. A procedure has been developed to selectively diagnose upper-air humidity from surface observations and to utilize both diagnostic and radiosonde data in an objective analysis of dew-point spread using the successive-approximation technique.

Northern-hemisphere surface-synoptic and radiosonde data from August through October 1964 are used to develop diagnostic relationships between surface-observed variables at a single station and the dew-point spread at the 850-, 700-, 500-, and 400-mb levels above that station for the warm season of the year. The approach consists of two steps: (1) the isolation within a decision-tree framework of those cases for which individual surface-observed variables yield highly reliable estimates of upper-level humidity, and (2) the application of a statistical technique (Regression Estimation of Event Probabilities) to the remaining cases to derive equations yielding probabilities of occurrence of specified categories of dew-point spread. This approach yields useful diagnostic information of variable quality.

The incorporation of diagnostic data obtained from the cold season relationships (derived in earlier work) into a humidity analysis at the 850-, 700- and 500-mb levels is tested using European surface and upper-air data for 22 observation times in February 1962. Sparse data conditions are simulated by withholding a portion of both surface and upper-air data.

Rms errors and contingency table percent correct scores indicate that an improved analysis is obtained by weighting the diagnostic data relative to the radiosonde data. The most appropriate weighting is a function of the reliability of the diagnosis and the data density.

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Regression Estimation of Event Probabilities						
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